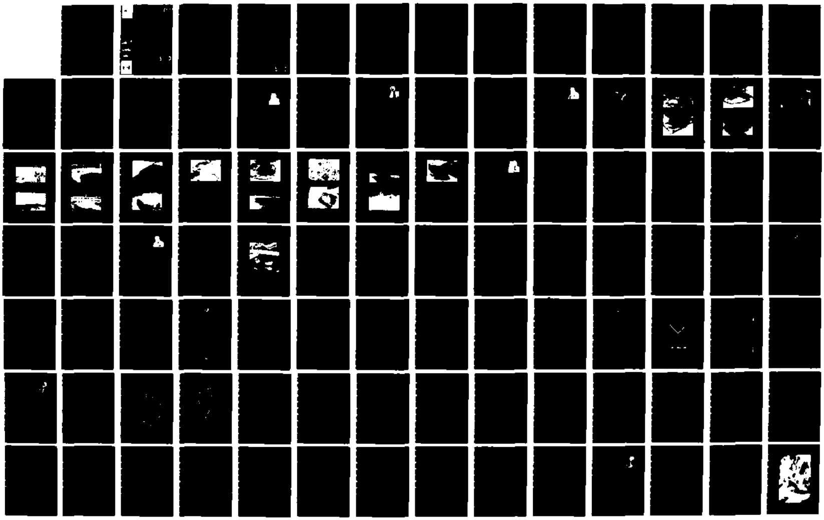
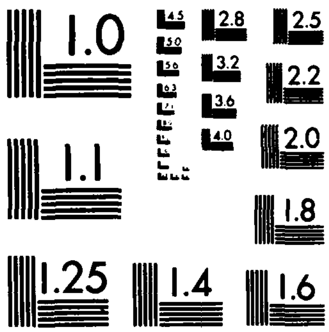
AD-A135 075 DREDGING OPERATIONS TECHNICAL SUPPORT PROGRAM AQUACULTURE IN DREDGED MATE..(U) ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS ENVIR.. 1/3

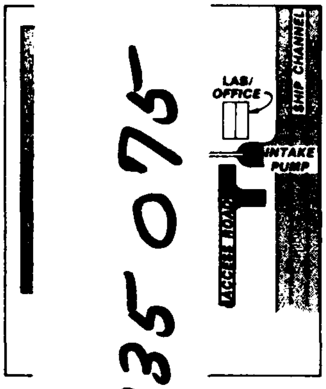
UNCLASSIFIED J HOMZIAK ET AL. OCT 83 WES/MP/D-83-2 F/G 13/2 NL



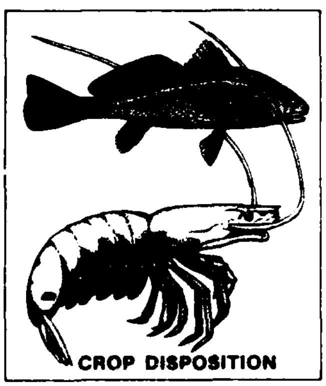


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

US Army Corps of Engineers



AD-A135 075



13

DREDGING OPERATIONS TECHNICAL SUPPORT PROGRAM

MISCELLANEOUS PAPER D-83-2

AQUACULTURE IN DREDGED MATERIAL CONTAINMENT AREAS

Proceedings

Jurij Homziak and John D. Lunz, Editors

Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

October 1983
Final Report

Approved For Public Release; Distribution Unlimited

Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314
and
U. S. Army Engineer District, Galveston
Galveston, Tex. 77553

This report series includes publications of the
following programs:

Dredging Operations Technical Support
(DOTS)

Long-Term Effects of Dredging Operations
(LEDO)

Interagency Field Verification of Methodologies for
Evaluating Dredged Mate~ial Disposal Alternatives
(Field Verification Program)

COMPONENT PART NOTICE

THIS PAPER IS A COMPONENT PART OF THE FOLLOWING COMPILATION REPORT:

(TITLE): Dredging Operations Technical Support Program, Aquaculture in Dredged Material Containment Areas, Proceedings Held at Galveston, Texas on September 1982.

(SOURCE): Army Engineer Waterways Experiment Station, Vicksburg, MS. Environmental Lab.

TO ORDER THE COMPLETE COMPILATION REPORT USE AD-A135 075.

THE COMPONENT PART IS PROVIDED HERE TO ALLOW USERS ACCESS TO INDIVIDUALLY AUTHORED SECTIONS OF PROCEEDINGS, ANNALS, SYMPOSIA, ETC. HOWEVER, THE COMPONENT SHOULD BE CONSIDERED WITHIN THE CONTEXT OF THE OVERALL COMPILATION REPORT AND NOT AS A STAND-ALONE TECHNICAL REPORT.

THE FOLLOWING COMPONENT PART NUMBERS COMPRISE THE COMPILATION REPORT:

COMPONENT PART NOTICE (CON'T)

AD#: TITLE:

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Miscellaneous Paper D-83-2	2. GOVT ACCESSION NO. AD-A134 075	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) AQUACULTURE IN DREDGED MATERIAL CONTAINMENT AREAS; Proceedings		5. TYPE OF REPORT & PERIOD COVERED Final report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Jurij Homziak and John D. Lunz, Editors		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Engineer Waterways Experiment Station Environmental Laboratory P. O. Box 631, Vicksburg, Miss. 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Dredging Operations Technical Support Program
11. CONTROLLING OFFICE NAME AND ADDRESS Office, Chief of Engineers, U. S. Army Washington, D. C. 20314 and U. S. Army Engineer District, Galveston Galveston, Tex. 77553		12. REPORT DATE October 1983
		13. NUMBER OF PAGES 216
		15. SECURITY CLASS. (of this report) Unclassified
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Aquaculture	Dredged material disposal
Aquaculture economics	Mariculture
Aquaculture laws and regulations	Pond design for aquaculture
Containment areas	Shrimp mariculture
Contaminated dredged material	Waste disposal sites
Dredged material	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The view that active dredged material containment areas (DMCA) are unproductive, commercially unusable, and incompatible with local needs can be challenged by demonstrating that there are situations where dredged material and DMCAs can be used to create positive benefits. One example would be a profitable and biologically productive use of disposal acreage for aquaculture. A 2-day workshop on aquaculture in DMCAs held in Galveston, Tex., in September

(Continued)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. ABSTRACT (Continued).

1982 and attended by representatives from the Corps, other Federal and State agencies, private industry, and academia, examined issues affecting the technical, legal, economic, and practical use of DMCAs for aquaculture.

The workshop concluded that:

a. Aquaculturists/entrepreneurs would benefit from access to DMCAs located near large markets, major transportation routes, and good water sources. Local interests could gain through increased employment opportunities and enhanced tax revenues. The profitable multiple use of a DMCA would benefit the land owner who would receive compensation for the use of his land as a disposal area and for aquaculture. In addition to improved land availability to assist in its dredged material management mission, the Corps would benefit from positive publicity generated by its efforts to cooperate with local interests.

b. DMCA aquaculture could be designed to produce salable, profitable crops or to produce fish or shellfish stocks for release to augment depressed natural populations.

c. Site development and pond management practices should be similar to those presently used in commercial aquaculture operations although important exceptions lie in the areas of site acquisition by entrepreneurs and permit-granting procedures.

d. Capital investment requirements could be significantly less due to simplified land acquisition, reduced land costs, and shared costs of dike construction and maintenance.

e. If a DMCA satisfied initial geotechnical and engineering requirements, constructing additional dikes, installing water control equipment, and other necessary modifications should follow procedures employed at conventional aquaculture operations.

The concensus among the workshop participants was that aquaculture as a secondary use of DMCAs would be both profitable and desirable. Field demonstration projects under various field conditions and research directed toward specific problem areas including contaminated sediments and site-specific limiting physical and chemical features were recommended as logical courses of action before applying the concept of DMCA aquaculture. The successful conduct and documentation of field demonstration projects were viewed as essential activities to respond to concerns about unreasonable risks caused by incompatibility of DMCA physical, chemical, and operation conditions with aquaculture.

PREFACE

Acquisition of new disposal areas and retention of existing ones has become increasingly difficult for many Districts of the Corps of Engineers (CE). The CE and other Federal government agencies maintain direct responsibility for providing disposal areas in more than 35 percent of the Nation's dredging projects. Although there is a growing trend toward local cooperation, the numbers of projects, the volumes of dredged material, and the acreages of dredged material containment areas (DMCA) managed solely by the Federal government are significant. Approximately 55 percent of the dredging projects in the New York District, and 70 percent of the dredging projects in the Philadelphia District, are totally sponsored by the Federal government. These projects produce an average annual volume of around 7 to 8 million and 6.5 million cubic yards of dredged material, respectively. In the New York District, while most of the dredged material from Federal projects is presently managed using open-water disposal, effort is constantly extended to identify alternative dredged material management options. In a limited number of instances, when the dredged material is suitable, it is used for beach replenishment. The Philadelphia District places most of its dredged material upland in approximately 9000 acres of DMCA. Nearly 8000 acres of these DMCA or 89 percent are wholly owned by the Federal government. Non-federal owners of suitable disposal acreage have historically viewed disposal areas as economically and biologically unproductive, leaving them reluctant to grant disposal easements to the CE. This negative view, that active disposal areas are unproductive, commercially unusable, and incompatible with local needs, can be challenged and refuted by demonstrating profitable and biologically productive uses of disposal acreage. One such biologically productive use identified by Corps Districts is aquaculture. The use of DMCA for aquaculture would directly benefit the CE in several ways. It would improve future site availability by increasing the value realized from the leased acreage, dispel the negative image of DMCA in the public eye, and generate a positive public image of the CE and its activities.

Aquaculture, as a productive use of dredged material containment areas, was first explored by the Corps of Engineers during the Dredged Material Research Program. In 1976, Dow Chemical Co., under contract to the Corps, successfully cultured a crop of shrimp in an active DMCA near Freeport, Tex. While this demonstration of feasibility was successful, technical difficulties and excessive costs made the operation unprofitable.

That conclusion is no longer valid. Continuing research in the biology and culture requirements of desirable species in aquaculture has reduced many of the technological stumbling blocks encountered during the Freeport demonstration. Concurrently, demand for seafood products and the expected profit from aquaculture operations have risen. The number of successful aquaculture operations nationwide, culturing a variety of species, has risen dramatically in the last several years. Under these circumstances, interest in aquaculture within the Corps has been renewed.

This publication presents the proceedings of a workshop designed to explore the feasibility and discuss guidelines for aquaculture in DMCA. The workshop was structured to assess the applicability of current aquaculture technology and then to provide recommendations and develop guidelines for profitable aquaculture operations.

The following were the specific objectives of the workshop:

- Assess the utility of current aquaculture technology and its possible application to DMCA aquaculture.

- Identify research needs in containment area aquaculture.

- Assess the aquaculture potential of contaminated containment areas.

- Discuss user guidelines for the establishment and operation of aquaculture facilities in containment areas.

- Propose designs for an economically attractive program of compatible multiple use for dredged material disposal and aquaculture in containment areas.

These proceedings acknowledge the efforts of many persons both within and outside the Corps of Engineers.

Messers. Jurij Homziak and John D. Lunz, U. S. Army Engineer Waterways Experiment Station (WES) Environmental Laboratory (EL), organized and conducted the workshop, edited the proceedings, and prepared the summary and conclusion sections. Dr. David Kendall, Dr. Drew Miller, and Mr. Dave Nelson, all of EL, contributed their organizational experience to the workshop planning.

The workshop and the proceedings were sponsored by the Dredging Operations Technical Support (DOTS) Program which is managed through the Office of Environmental Effects of Dredging Programs (EEDP). Mr. Charles Calhoun is the EEDP Manager; Mr. Thomas Patin, EEDP, assisted in the conduct of the workshop.

The U. S. Army Engineer District, Galveston, co-sponsored the workshop and provided special support at the workshop location.

The cooperation and support of Messers. David Mathis and William Murden, U. S. Army Engineer Water Resources Support Center, Dredging Division, and Mr. Jesse Pfeiffer, Office of the Chief of Engineers, Directorate of Research and Development, are gratefully recognized.

The cooperation and assistance of the workshop speakers, moderators, panelists, and participants contributed to the development of the proceedings.

The Galveston District Engineer during this workshop was COL Alan L. Laubscher, CE. Commander and Director of WES was COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

SUMMARY

Parties involved in commercial containment area aquaculture could realize significant benefits from multiple use of dredged material containment areas (DMCA). Freshwater and coastal DMCA offer the benefits of desirable location (often near large markets and on major transportation routes), access to good water sources, and reduced construction and maintenance costs to aquaculturists/entrepreneurs. Local interests could gain from the development of DMCA aquaculture through increased employment opportunities and enhanced tax revenues.

A financially profitable multiple use of containment areas would benefit owners of disposal acreage and, through increased site availability, would benefit the Corps of Engineers. The property owners would receive compensation for the use of their land initially as a disposal area as well as through subsequent operations by aquaculture interests. This would serve as a financial incentive to other property owners to make acreage more readily available for disposal. In addition to the improved real estate availability, the Corps of Engineers would benefit from the positive publicity generated by its efforts to cooperate with local interests and from promoting the productive use of what had heretofore been popularly perceived as biologically and economically unproductive acreage.

Aquaculture Products

Aquaculture in DMCA could be designed to produce crops for commercial harvest or the culture efforts could be directed towards the production of fish or shellfish stocks for release to augment depressed natural populations. Current aquaculture-for-release programs in California, Texas, Japan, and the Middle East use natural and artificial coastal ponds, lagoons, and embayments for their propagation programs. Similar programs could easily be undertaken in DMCA.

Previous work with the culture of fish and shellfish in coastal impoundments and containment areas can serve as prototypes illustrating the feasibility of DMCA aquaculture. Crops of fish, shrimp, crab, and crawfish raised with minimal management effort have been harvested from old rice field impoundments in South Carolina. A DMCA in Sabine Lake, Port Arthur, Tex., produced marketable crops of redfish, shrimp, and crab, again with little management effort. Shrimp cultured in an active DMCA near Freeport, Tex., research undertaken as part of the Dredged Material Research Program of the Corps of Engineers, were found to grow well and produce a wholesome crop when nurtured solely on dredged material. To emphasize the continuing interest in impoundment/containment area aquaculture, at least three commercial concerns represented at the workshop have leased such acreage for aquaculture development.

Areas of Concern

Site characteristics

Containment areas vary considerably among themselves. Location, size, construction, compatibility of mariculture with disposal requirements, and a myriad of other site-specific physical and chemical features effectively make each DMCA unique. While not all DMCA will be suitable for aquaculture, a significant number have the proper combination of features to support aquaculture. Crucial to the development of aquaculture as a secondary use of DMCA is that aquaculture operations will be possible only if they are compatible with the disposal requirements and schedule imposed by the intended primary use of the site--dredged material disposal. Only when the aquaculturist's and the disposal agencies' requirements are met can a site be developed for aquaculture.

Site acquisition and permitting

Site development and pond management practices are expected to be similar to those presently used in commercial aquaculture operations. Major exceptions lie in the areas of site acquisition by entrepreneurs and permit granting procedures. In the first case, existing easement agreements must be considered, requiring prospective aquaculturists to reach separate agreements with both the property owner and the Corps of Engineers. In the second case, representatives of commercial aquaculture enterprises claimed that the current permitting process is so involved and complex that the growth of aquaculture in the United States is effectively thwarted. Having the Corps of Engineers involved in the promotion and development of aquaculture in addition to retaining its traditional role in the permitting process should, in the view of many of the workshop participants, expedite the process in the future.

Use of contaminated sediments

The question of sediment contaminants and their possible effects on cultured organisms was another important area of concern. Material dredged from areas with high levels of navigation traffic usually contain contaminants. The results of recent experiments designed to assess the effects of high contaminant concentration on marine and freshwater organisms suggest that even high contaminant levels in sediments do not necessarily produce toxic effects in test organisms nor do they promote the accumulation of large concentrations of contaminants in the tissues of these organisms. Of course, these results vary with the type of contaminant, sediment conditions, and species of organism involved. While information is lacking on many aspects of contaminant effects on species of interest to aquaculturists, this was not viewed as an insurmountable problem. Caution and additional research were advised in dealing with potentially contaminanted sediments.

Economics

From an economic viewpoint DMCA aquaculture appears favorable. Participants with experience in both finfish and shrimp culture pointed out the great degree of similarity in the economic and marketing requirements between current aquaculture operations and those proposed for DMCA. Capital investment requirements could be significantly reduced. Simplified land acquisition, reduced land costs, shared cost of dike construction and maintenance expenses, and expedited permitting process would all contribute to reducing

capital cost. Operating costs, dependent on both site and species cultured, were not so readily analyzed, but no extraordinary additional costs were anticipated.

Physical plant

Pond construction and modification for aquaculture would also be site- and species-specific. Given that a DMCA satisfied initial geotechnical and engineering requirements, the construction of additional dikes, installation of water control equipment, and other necessary modifications should follow the procedures employed at conventional operations. Cooperative efforts involving aquaculturists, the U. S. Department of Agriculture Soil Conservation Service, and the Corps were recommended for developing the design and specifying any modifications necessary for the use of DMCA for aquaculture.

Management concerns

Water quality, health concerns, and species management techniques for DMCA culture should be identical to current practices, although the effects of large amounts of fine sediment in the containment area ponds and the lack of experience in managing large-scale aquaculture operations were questions that still need to be addressed. Management procedures for large ponds have not been developed for many species simply because large ponds have not been generally available. With increased availability, such as by the widespread use of DMCA acreage, appropriate techniques will rapidly evolve. Similarly, adequate water exchange, aeration, and harvest techniques should overcome any difficulties created by the presence of large amounts of fine sediments.

Compatible activities

Dredged material disposal and aquaculture may coexist in several ways. Crops may be cultured between disposal events, as in the Freeport demonstration, or the DMCA may be subdivided into cells to be filled sequentially, permitting concurrent aquaculture and disposal operations in separate cells. With either system, aquaculture operations would cease as the containment area approached capacity.

Prospects of Success

The needs of the local area, interests of the involved parties, and technical constraints will determine which type of culture operation (commercial or stock augmentation) and which species would be most suitable for a given area.

The prospects for culture of freshwater fish in DMCA are bright. The large successful industries centered on crawfish, catfish, trout, and bait minnows can provide both the technical expertise and the sources of stock needed for development of a profitable operation. The technology involved in freshwater fish culture is both well defined and compatible with culture plans envisioned for DMCA.

Redfish, exotic and native shrimp, trout, bait shrimp and minnows, and waterfowl are the most promising species for marine/brackish water culture. Unlike the freshwater species, the technology for the culture of many marine species has only recently advanced to the commercial level. The closing of

shrimp life cycles under laboratory conditions, developing redfish propagation techniques, and other recent biological advances permit a cautiously optimistic assessment of the prospects for the culture of these marine species.

The most logical way to advance the development of DMCA aquaculture technology will be through the experience of field demonstration trials conducted in different geographic and operational settings. The strong technological and marketing experience of the aquaculture industry and the results of demonstration activities would together produce the credible guidance necessary for the concept to be applied nationally.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acres	4046.873	square meters
cubic feet	0.02831685	cubic meters
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
gallons per minute	3.785412	cubic decimeters per minute
gallons (U. S. liquid)	3.785412	cubic decimeters
horsepower (550 foot-pounds per second)	745.6999	watts
inches	25.4	millimeters
inches per hour	25.4	millimeters per hour
miles per hour (U. S. statute)	1.609347	kilometers per hour
miles (U. S. statute)	1.609347	kilometers
pounds (mass)	0.4535924	kilograms
pounds (mass) per acre	0.000112	kilograms per square meter
pounds (mass) per acre-foot	0.000367	kilograms per cubic meter

AQUACULTURE IN DREDGED MATERIAL

CONTAINMENT AREAS

PROCEEDINGS

WELCOME

by
COL Alan L. Laubscher
District Engineer
U. S. Army Engineer District, Galveston
Galveston, Texas 77553

COL Alan L. Laubscher

Good morning and welcome. It is my pleasure this morning to welcome you to the workshop on Mariculture in Dredged Material Containment Sites, and to welcome you to Galveston District and Galveston Island.

I certainly believe that Galveston is an appropriate site for the workshop: all of us today are standing on an island made up in large part of dredged material.

To explain a little further about my comments on dredged material, I would like to give you just a brief history of Galveston Island. Some of the first inhabitants of the island were the Karankawa Indian tribe, a kind of unfriendly group. The next group that occupied the island was equally unfriendly in that it was Jean Lafitte and some of his cohort pirates. They established a settlement here in about 1817.

After Lafitte was ordered off the island by President James Monroe, Galveston developed very rapidly, based on its rather natural port facilities. It became the primary city and leading complex in this part of the world.

And then it happened! On the afternoon of September 8, 1900, the city and its 38,000 residents came close to being literally wiped off the face of the map. The 1900 hurricane rolled across the island with 15-ft tides and winds of 91 mph.* When the smoke all cleared, 3600 buildings had been destroyed, some $25 million in damage had occurred, and some 6000 people lost their lives.

The citizens of Galveston faced a tremendous task of rebuilding from the shambles after the hurricane. In 1901 the city commissioners selected

---

* A table of factors for converting U. S. customary units of measurements to metric (SI) is presented on page ix.

a Board of Engineers to develop a protection system for the city, and the Galveston seawall, which you have undoubtedly noticed just a few blocks from this building, was part of that protection plan. A second contribution of that board was an almost unprecedented task of raising the grade of the entire City of Galveston. The job of raising the elevation to about 17 ft near the seawall and sloping off to the bay was accomplished with dredged material. So, in fact, we are standing here today on dredged material.

Next, to set the scene for your conference and to scope the magnitude of the dredging program, I would like to tell you something about the dredging program here in the Galveston District.

The Galveston District contains approximately 1000 miles of navigable waterways along the Texas coast, about 720 miles of shallow draft channels, and 240 miles of deep draft channels. The operations and maintenance budget for this District is about $50 million a year for dredging approximately 40 million cubic yards of material from navigable waterways each year.

The District requires over 48,000 acres of disposal area to accommodate the material dredged from the Gulf Intracoastal Waterway and its tributaries along the 400-mile Texas coastline. This figure includes both diked containment sites and open-water disposal sites. As a result, we here in the Galveston District are very interested in the development of productive uses of disposal sites.

In the past we have had a part in several dredged material research programs, including the Bolivar Habitat Development Program, a test site on the Texas City dike. Also, a demonstration shrimp mariculture program was conducted at Freeport. We in the Galveston District are pleased to share these experiences with you during this conference.

Dredged material and its productive uses can be classified as one of the major challenges facing the Corps of Engineers today. You have an important task ahead of you, and I wish you every success in your efforts. With these very few words, I want to say welcome to all of you and I wish you good luck.

OPENING REMARKS

by
Jesse A. Pfeiffer, Jr.
Directorate of Research and Development
Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

J. A. Pfeiffer, Jr.

ABSTRACT

The Corps of Engineers, by virtue of its responsibilities in waterway maintenance, is in a unique position to promote the development of aquaculture in its disposal areas. Recent advances in the biology and culture requirements of many desirable species, coupled with favorable economic circumstances, have renewed interest in aquaculture within the Corps. While the Corps has no direct interest in aquaculture, it does have an interest in developing productive uses for disposal areas. By demonstrating the profitable use of dredged material containment areas (DMCA), the value of such property would increase. Increasing profits would induce owners of suitable acreage to make additional disposal areas available. Productive use of DMCA, increased lease values, cooperation between governmental agencies, and favorable publicity are the Corps' benefits. Aquaculturists would benefit from increased availability of suitable acreage, reduced land costs, reduced construction costs, and Corps cooperation. Public benefits would be in the form of increased tax revenues, employment opportunities, and indirect economic stimuli.

I want to add my welcome to that of COL Laubscher. We are very pleased by the interest in this workshop. We have people from the Corps of Engineers, from private industry, from universities, and from other government agencies; Federal, state, and local.

I would like to develop the background for this national workshop on aquaculture in our dredged material containment sites. In doing so, I will emphasize several aspects: the legislative background, the Corps' mission, and the Corps' research and development program. Then I would like to

discuss how these relate to the Corps' renewed interest in aquaculture and some of the benefits we think can be realized from aquaculture in dredged material containment sites.

The Corps' interest in dredging comes from its legislative mandate in navigation. Therefore, the Corps does not have a direct interest in aquaculture--the interest stems from its basic mission in navigation. Historically, this navigation mission entailed both construction and operations activities and has been recently broadened to include regulatory responsibilities, many of which affect aquaculture. We are primarily interested in relating aquaculture to the Corps' navigation mission. The maintenance of harbors and navigation channels is a necessary and ongoing task. The budget for new work and maintenance exceeds one-half billion dollars annually. Dredging to keep harbors and navigation channels open produces dredged material which must be disposed. This disposal is a constant problem due to the difficulty of acquiring disposal sites. There is opposition to open-water disposal, upland and coastal acreage may be prohibitively expensive, and there is often resistance to disposal on the local level. Channel maintenance often produces little benefit for the local population while requiring it to bear the burden of material disposal. An example of this would be an intracoastal waterway where the local population does not directly benefit.

Another hindrance to the acquisition of sites is that dredged material containment areas are not viewed very favorably. They are viewed as biologically and economically nonproductive. There are also fears of contaminants within these dredged material containment areas. In general, their presence may be considered noncompatible with local biological and environmental aims.

In the middle '70s little was known about the impacts of dredged material disposal. From 1973 to 1978 Congress directed the Corps of Engineers to conduct what was known as the Dredged Material Research Program (DMRP). This research program was broadly based and studied various aspects of dredged material, its characteristics, impact, and possible productive uses. The DMRP provided a foundation for understanding the effects of dredged material disposal. Although the DMRP answered many critical questions, it raised many more. As an example, one area of research was a feasibility study of shrimp aquaculture conducted at Freeport, TX. Although it established the feasibility of such a project, it left many unanswered questions, questions this workshop was designed to explore.

From 1978 to the present, the Corps has tried to apply the technology developed during the DMRP through a program known as Dredging Operations Technical Support (DOTS). This workshop to assess the feasibility of aquaculture is being conducted under the auspices of the DOTS Program. Another program initiated this year to study the long-term effects of dredging operations, such as possible subtle and sub-lethal effects of dredged material disposal, may also contribute to the aquaculture area.

What are the reasons for the Corps' recent interest in aquaculture? We think that aquaculture is an attractive idea for a variety of reasons. There is a demand for aquaculture products due to declining "luxury" fish stocks, increased costs of U.S. caught and imported fish products, increased demand for seafood (especially in the restaurant trade in the United States), and a dependence on imported seafood to satisfy U.S. demand. The technology for the culture of many species has been unavailable until recent improvements in culture techniques have made the culture of many desirable species

possible. This has all happened since we first studied the feasibility of shrimp mariculture back in the middle '70s. The economics of aquaculture, with increasing demand and decreasing wild stocks, are more and more favorable. Congress recognized this and passed the national Aquaculture Act of 1980 requiring the development of a national aquaculture plan. That plan is in draft now and will soon be available to the nation.

The Corps of Engineers, by virtue of its responsibilities in waterway maintenance, is in a unique position to develop aquaculture in its dredged material containment areas. Dredged material containment areas must be designated in advance of any maintenance program and the sites often have a long active life--10, 20, even 50 years--making multiple use of the site possible.

The cost of land may be reduced. Coastal or estuarine property, suitable for mariculture, is often prohibitively expensive. Construction and other capital costs may be reduced. For example, construction may be modified to permit internal pond diking or the placement of drainage ditches at minimal cost to the aquaculturist. The multiple use of sites for disposal and aquaculture has shown to be feasible based on information from the DMRP and from pilot-scale commercial operations in Texas and South Carolina.

Productive use is something in which we are interested. It fits the current administration's outlook on productive returns. Although the primary role of dredged material containment areas is to contain dredged material, it is a passive role. If these sites could be used for productive multiple use, it would be good for everyone.

We think there are benefits to be realized by all the involved parties if this concept can be developed and applied. First, there will be benefits to the public. It could provide local employment and an economic stimulus. It could increase the value of the land that the site is on. There are certainly some benefits to the Corps of Engineers. An aquaculture option would provide the landowner, which is often a local governmental body, with reasonable compensation for use of the disposal site. The favorable and economically attractive multiple uses of a containment site could improve the availability of disposal acreage. It may make a difference to a landowner or to a local government if some productive use could be derived from a site instead of having it lie unproductive for years. The Corps would also gain some positive publicity and it would promote cooperation between governmental agencies involved in aquaculture.

There are other possible benefits, but these are some of the more obvious. There are, of course, still a lot of questions with regard to the full potential of aquaculture in a dredged material containment area: economic questions, pond management questions, biological questions, contaminant questions. We hope to address these during the course of this conference.

I would like to encourage a lively participation and interchange so that we all will benefit from this conference. Thank you very much.

SITE DESCRIPTION OF DREDGED MATERIAL CONTAINMENT AREAS: AN OVERVIEW OF PHYSICAL, CHEMICAL, BIOLOGICAL FEATURES

by
Rick Medina
U. S. Army Engineer District, Galveston
Galveston, Texas 77553

Rick Medina

ABSTRACT

Dredged material containment areas (DMCA) differ physically, biologically, and chemically. Structural variability includes size, configuration, foundation conditions, water retention properties, and the presence of interior cells. Levees differ in height, width, continuity, and adaptability to aquaculture. Locations may be remote or have ready access to roads and commercial power sources. Water control structures vary in location, state of repair, and usefulness to the prospective culturist. Infrequently used DMCA may be heavily overgrown, while active DMCA, containing sand, silt, or clay, often have irregular bottom topography and potentially unstable interior soils. Most DMCA are biologically productive during inactive periods, but potential contaminants within or scheduled for disposal in DMCA should be assessed. The length of time an area is active and the frequency of disposal, important impacts in DMCA aquaculture activities, should be incorporated into all planning. Cooperation from the local Corps District is anticipated.

The purpose of my talk this morning is to present an overview of the different types of dredged material containment areas that exist, and some of their physical, chemical, and biological characteristics. Through a series of figures, I hope to show some of the features you may need to consider in selecting a dredged material containment area for a mariculture operation. While these figures are specific to the Galveston District (Figure 1), I believe they can be typical of many sites you can expect to find across the country or at least along the gulf coast.

Figure 1. Galveston District logo

As Colonel Laubscher mentioned, the Gulf Intracoastal Waterway requires over 48,000 acres of disposal areas of which nearly 20,000 acres are confined. District-wide there are nearly 50,000 acres of confined or partially confined areas. Obviously, many of these areas are not going to be conducive to a mariculture operation. The site you select will be influenced by a variety of factors. I hope to point out some features of disposal areas you may wish to consider before selecting a site.

Typically, dredged material disposal areas will be confined, partially confined, or open water. A confined area (Figure 2) as you might expect, is completely encircled by a levee system. A partially confined area (Figure 3) will have some sort of levee system but will have an opening to allow for tidal exchange. At this area, the opening in back was by design. Erosional forces, however, have cut an opening in the front. Disposal areas are sometimes divided into cells (Figure 4). In this manner, material is deposited into one cell, and the excess water overflows into a second or third cell before exiting the disposal area. This area is unique in that it involves a confined upland area, the dark area on the right, a confined tidal area in the upper half of the figure with tidal opening through a spillway, and the larger partially confined tidal area.

The size of disposal areas is variable. Some areas are as small as 15 acres. At the other extreme, there are some very large areas. Figure 5 is an area over 3600 acres. The area is so large, we could not get it all in the figure. As you might expect, 3600-acre sites are an exception. Most sites will be several hundred acres or less.

An important feature of all the sites is their accessibility. Some areas are near roads and can be driven to easily (Figure 6). This area is bounded by roads on three sides and you can actually drive up on the levee itself. Sites such as these offer the advantage of easy access for set up, operation, and maintenance of your activity. They offer a disadvantage in that they are accessible to anyone and everyone. Other sites are more remote and are accessible only by water transportation. These sites offer an

Figure 2. Old Snake Is and Cell B

Figure 3. HSC, DA 14

Figure 4. Snake Island

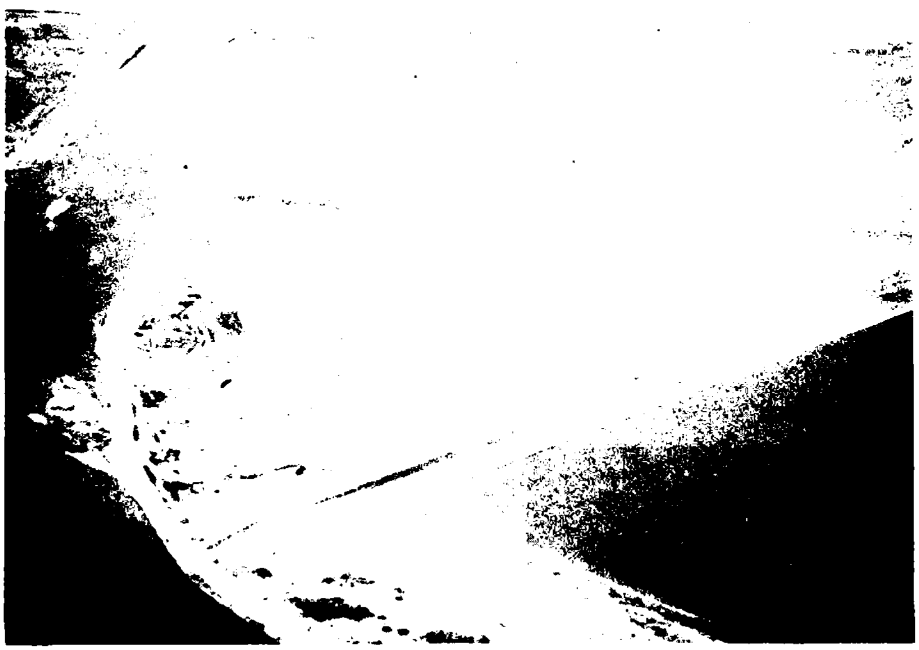


Figure 5. DA 86

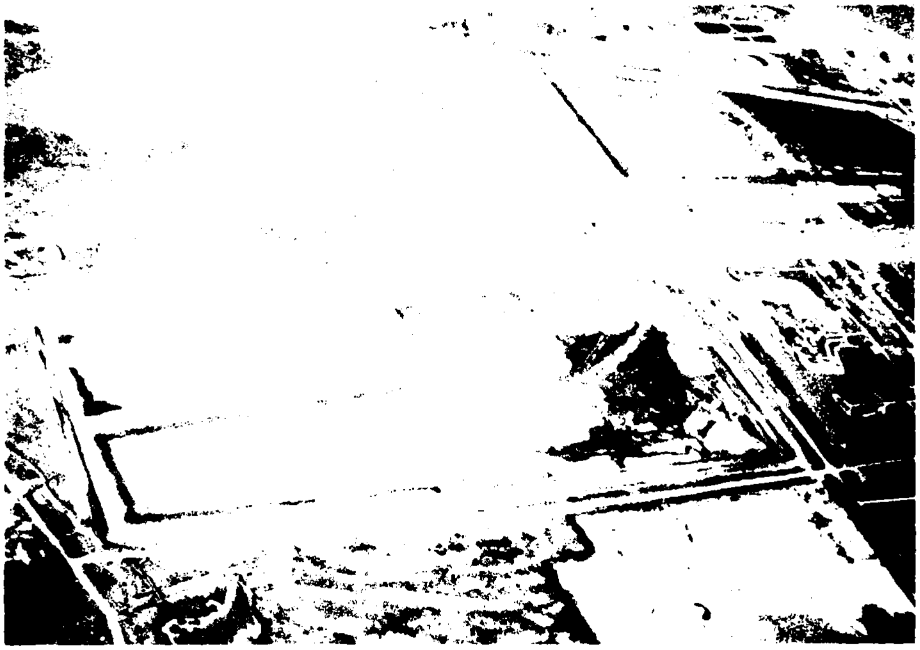


Figure 6. SNWW, DA 8

advantage in that they are not accessible to the general public, but will present logistical disadvantages to operation of the activity in terms of transporting equipment and manpower to the site.

The levee height at any disposal area can vary from about 5 feet above sea level (Figure 7) to nearly 50 feet above sea level (Figure 8). The levee height can greatly influence the energy requirement necessary if water must be pumped into the area. Within each disposal area there may exist different types of cross levees or training levees. These training levees are usually smaller than the perimeter levee and are used to provide maximum ponding before the water exits the spillway.

Each confined area usually has a spillway structure through which ponded water can be drained from the area. As the area fills up, boards are inserted on the sides, and the ponded water overflows through the spillway and out the drain pipe. There are two types of spillway structures which can be found at a disposal area. The weir type (Figure 9) is located within the levee perimeter system itself. The drop inlet type (Figure 10) is a separate structure located just within the levee perimeter. The drop inlet type spillway is the most common. The quality of the spillway at each area will also vary.

The type material deposited within the areas can range from sand (Figure 11) to silt (Figure 12) to clay (Figure 13). In addition, the chemical composition of the material has also been determined. Samples are tested for a variety of heavy metals and pesticides. In some cases, bioassays of the dredged material have been performed. The results of these tests have shown that pollutants are not resuspended as a result of dredging and are generally unavailable for uptake by marine organisms. I should point out,

Figure 7. Double Bayou levee

Figure 8. Seaway DA levee

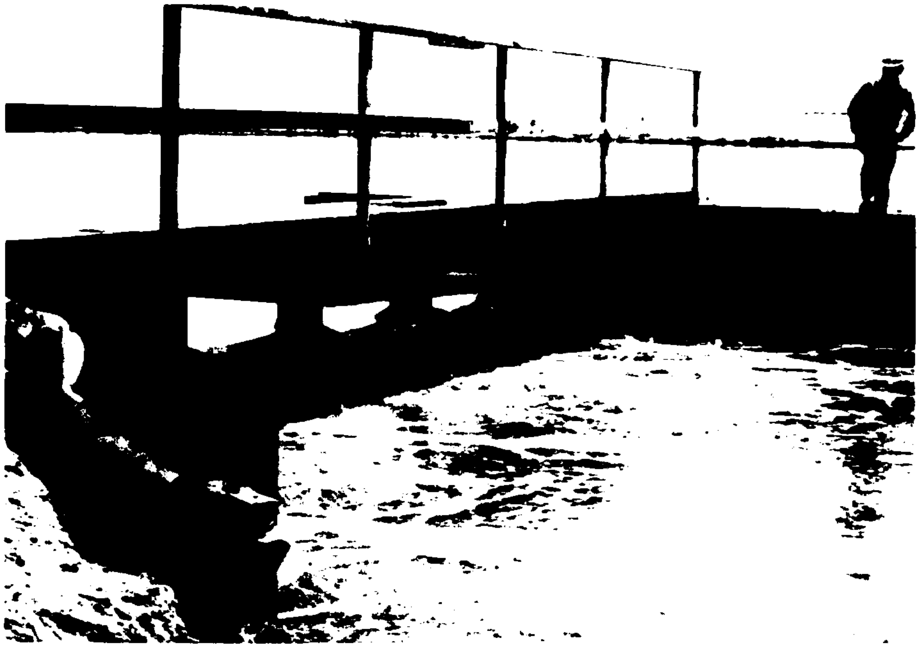


Figure 9. CCSC, DA 1, weir

Figure 10. DA 85, SPW

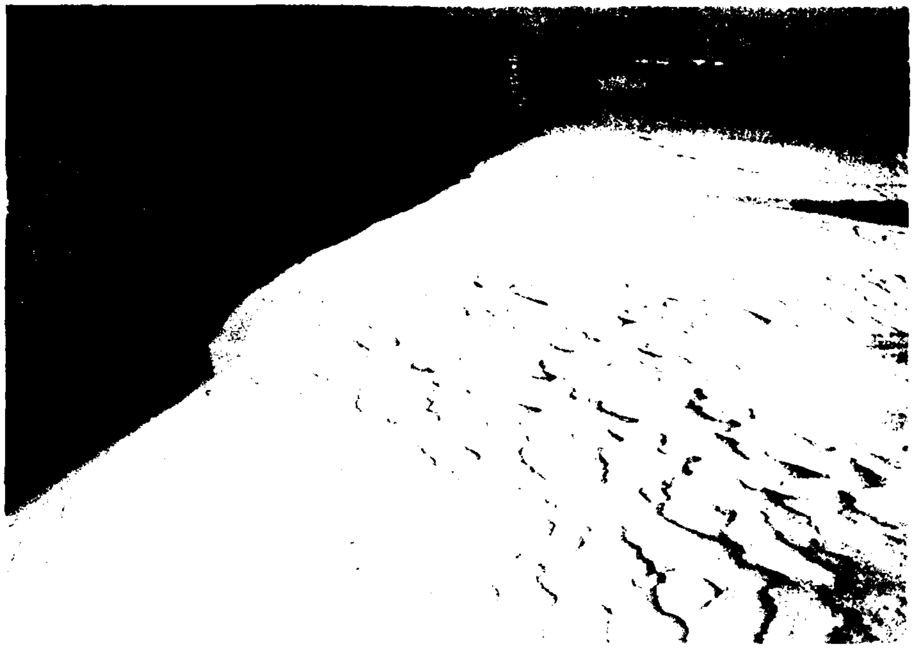


Figure 11. DA 8, Pt. Mansfield

Figure 12. HSC, Clinton DA

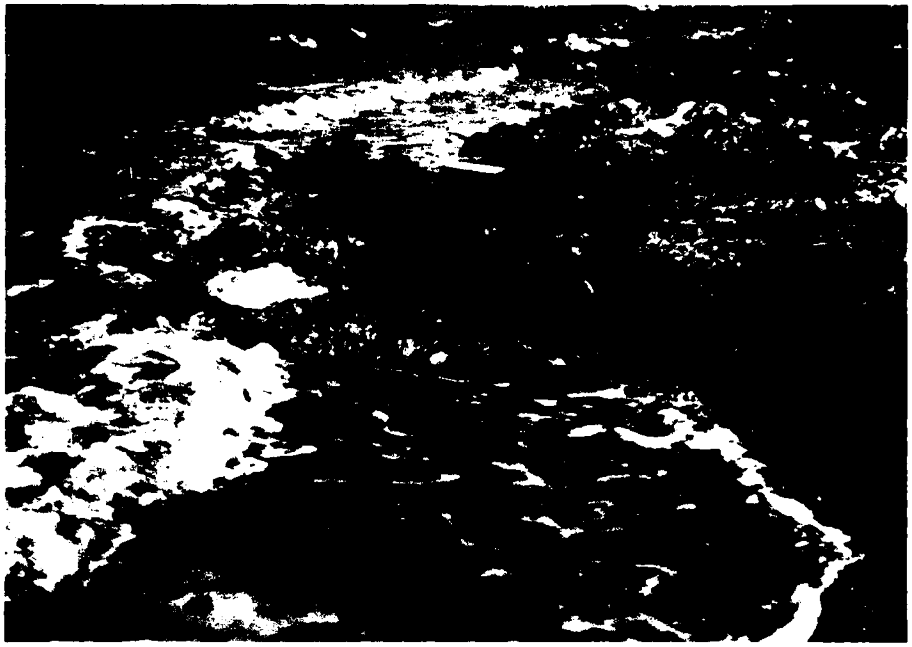


Figure 13. Snake Island levee

however, that these tests are specific to the dredged material prior to disposal. They do not take into account any changes in the material after disposal. These changes can include effects due to leaching, oxidation, or input of other material. Therefore, you may wish to consider more detailed testing of the material as part of your site selection criteria.

Within the disposal area itself, you may encounter a flooded condition (Figure 14). The length of time which an area remains flooded will be determined in part by drainage patterns within the site and rainfall events. You may also encounter a desiccated area (Figure 15). In fact, this is the same area as shown in Figure 14, 8 months after dredging. In these areas the surface layer will dry out, crack, and form a crust (Figure 16). Water will become trapped beneath this surface crust. Consequently, the ground is unstable and has poor foundation qualities.

The disposal areas do provide some benefit to the environment. The tidal areas provide feeding and nursery areas for aquatic organisms (Figure 17) and birds (Figure 18). If enough time has passed since disposal, the areas will revegetate naturally. These revegetated upland areas can provide habitat for birds and other wildlife (Figure 19). Infrequently used areas can be heavily overgrown and will have to be cleared before use.

There is one other important aspect that you must consider in using a dredged material containment area for mariculture operations, and this is that one day the area will again be used for disposal (Figure 20). A dredging job can last from a few weeks to over a year. The length of time and the frequency that an area is used for disposal is a function of the volume of material to be dredged and the proximity of other disposal areas.

Figure 14. Old Snake Island

Figure 15. Dry Snake Island

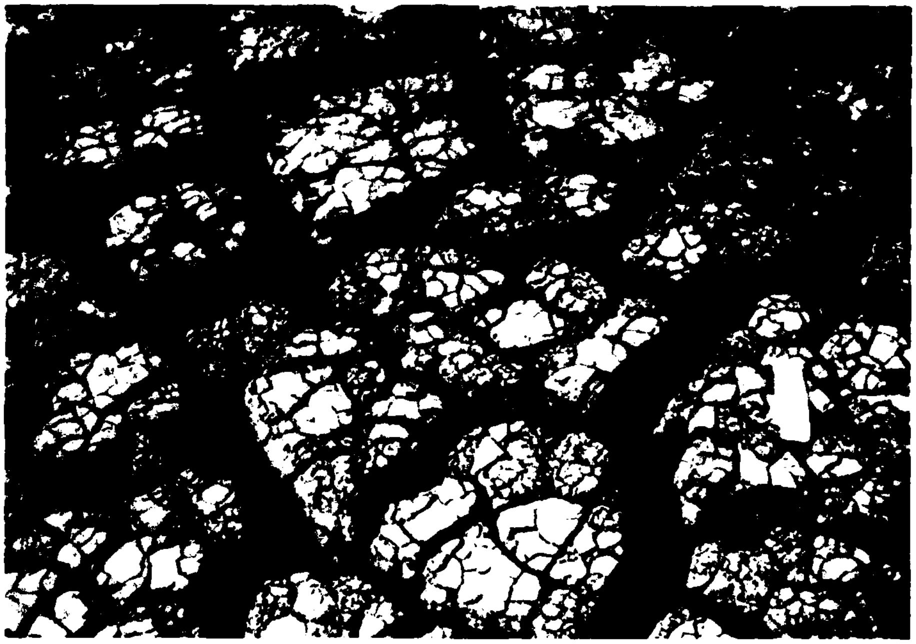


Figure 16. Desiccation cracks

Figure 17. Shrimp catch

Figure 18. North Deer Is. birds

Figure 19. Bolivar, thick vegetation

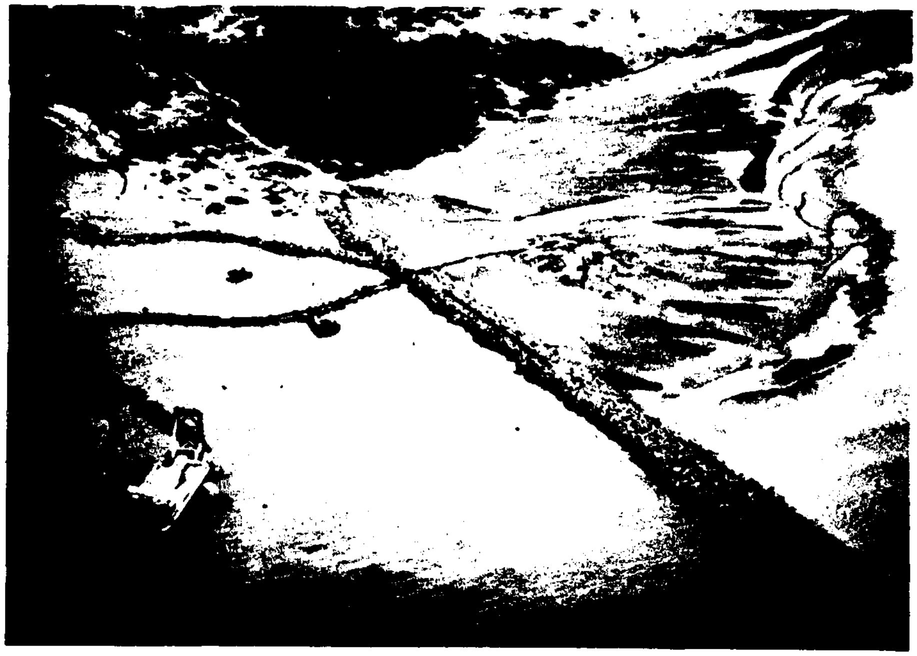


Figure 20. Dredge pumping material

Finally, I do not want to leave you with the impression that we will come in and indiscriminately wipe out 3 or 4 years of your effort. I believe you will find most Districts will work with you, on a case-by-case basis, to minimize impacts to your operation as well as to provide for the disposal of dredged material.

AD P002130

APPLICABILITY, COSTS, AND BENEFITS OF MARICULTURE IN CONTAINMENT AREAS

by
John D. Lunz
Waterways Experiment Station
P. O. Box 631
Vicksburg, Mississippi 39180

John D. Lunz

ABSTRACT

Questions and answers concerning the applicability, costs, and benefits of aquaculture in actively used dredged material containment areas are generally discussed. The concept of containment area aquaculture has been studied before. The objective of previous work was to determine whether commercially important penaeid shrimp would survive and grow in a dredged material containment area. The concept is being reviewed again because (a) the state of the art of aquaculture technology has significantly advanced during the last decade; (b) the acquisition of suitable dredged material disposal acreage is probably the most common dredging-related problem among Corps of Engineer Districts; and (c) the multiple, beneficial use of dredged material disposal sites for aquaculture and disposal operations is an intriguing management option that would benefit government, the public, industry, and the environment.

INTRODUCTION

Speaking as a scientist who, during the development of ideas and events leading to this workshop, has become involved in aquaculture for the first time, I have noticed there is something alluring about American aquaculture. It has the characteristics of an adventure; it appeals to American instincts for technology application, independence, and potential wealth.

It's easy to generate a list of simple and not-so-simple facts or benefits that make American aquaculture attractive. For example, a U. S. Department of Agriculture Publication identifies the following:

a. Fish provide a nutritious addition to the American diet.

b. Aquaculture could reduce the U. S. trade deficit and concurrently help satisfy the world's growing need for animal protein.

c. Aquaculture can provide additional stability and diversification for U. S. agriculture and agribusiness via employment in fish farms, feed mills, processing plants, and other supporting industries.

d. Aquaculture can augment fish stocks for commercial and sport fisheries that have declined due to exploitation, pollution, and habitat destruction.

There appears to be something here for everyone: the hourly wage worker, the political strategist, the world's poor and hungry, the lobster lovers of America who do not live in New England, and the U. S. budget.

The bothersome thing is the subjunctive nature of the statements. Most often I hear and read about what aquaculture would do or could do. What we need to accomplish and what we hope to achieve at least in-part by the end of this workshop is the development of statements that are less suppositional and more factual, and that concern the application, the costs, and the benefits of aquaculture in the particular physical, chemical, and operational environment characteristic of a dredged material containment area.

APPLICABILITY

First we must ask some questions:

a. Are dredged material containment areas suitable or can they be made suitable for aquaculture?

b. Is the state of the art of the aquaculture technology, when applied to containment area conditions, compatible with contemporary American views of reasonable risk and reasonable profit?

c. Is periodic dredged material disposal compatible with aquaculture?

Next we must consider responses from different parties. These parties would need to be considered during inquiries concerning application or costs or benefits: First there is the agency requiring the containment area for the disposal of dredged material--most often this is the Corps of Engineers in cooperation with the project's sponsor, usually a port authority or municipal government. Next, the person or organization who would conduct the aquaculture, and, finally, the owner of the real estate on which the containment site is located.

The Productive Uses Project of the Corps' Dredged Material Research Program (DMRP) conducted by the Waterways Experiment Station from 1973-1978 sponsored a field demonstration of shrimp mariculture feasibility in dredged material containment areas. The demonstration was performed by Dow Chemical U. S. A. in Freeport, Tex., and the results are published in the familiar-to-some-of-you series of gold-covered DMRP reports.

Mr. Dennis Milligan, one of the principals from Dow Chemical involved in that project, is on our program and I don't want to scoop him in case he intends to refer to results of that study. I will simply say that white shrimp were raised in a dredged material containment area, growth and survival

were both satisfactory without supplemental feeding, the National Marine Fisheries Service declared the shrimp as wholesome for human consumption, and the shrimp were consumed.

An aquaculture or mariculture operation will be situated in an upland location which, under ordinary conditions, is not flooded by tidal waters or other waters; or it will be situated in a location that is ordinarily flooded on a regular basis. The Freeport, Tex., demonstration represented a condition that would be most accurately described as semi-intensive culture in an upland disposal area. For contrast, in Sabine Lake, Tex., the City of Port Arthur owns in excess of 5000 acres of tidally flooded disposal site real estate that is used to contain the maintenance dredged material from the Sabine-Neches Waterway. Persons representing both the government of the City of Port Arthur and Moon Aquaculture Foods, Inc., which has been harvesting fish and shrimp from one of the Port Arthur sites for the last 2 yr, are present at this workshop and can attest to the site's natural productivity without management.

Nationally, upland dredged material containment sites are much more numerous than subtidal or intertidal sites. This situation is unlikely to change in the future because Federal, State, and local laws, regulations, and ordinances affecting environmental protection and land use restrict the use of intertidal or subtidal sites for disposal.

Interestingly, most regulatory controls regulate the use of containment sites that have been filled to capacity. Their applicability to containment sites during active disposal life is as yet undetermined. If the existing regulatory controls are applicable to active containment sites, the following would be pertinent (Federal laws, for the most part, have an indirect impact on dredged material containment areas, acting largely to guide and influence State and local legislation):

Coastal Zone Management Act of 1972 (16 USC Section 1451 et seq.; Pub. L. No. 92-583; 86 Stat. 1289).

National Environmental Policy Act 42 USC Section 4341; Pub. L. No. 91-190)

Federal Water Pollution Control Act (33 USC Section 1251 et seq.; Pub. L. No. 92-500).

Clean Water Act of 1977 (Pub. L. No. 95-217; 91 Stat. 1566).

Endangered Species Act of 1973 (Pub. L. No. 93-205; 87 Stat. 884).

Fish & Wildlife Coordination Act [16 USC Sections 661-666; Pub. L. No. 85-624 (1935)].

Resource Conservation and Recovery Act of 1976 (42 USC Sections 3251 et seq.; Pub. L. No. 94-580).

National Flood Insurance Act of 1968 (Pub. L. No. 90-448).

Wild and Scenic River Act (16 USC Sections 1274 et seq.; Pub. L. No. 94-486).

State and local laws constraining containment area location and disposition fall into two categories:

_a_. Laws directed at environmental protection:

1. Wetlands protection laws (includes shoreline or coastal and freshwater wetlands laws)

2. Water quality laws

3. Wild and scenic river system laws

4. Wild lands protection or land conservation laws

5. Fish and game habitat protection laws

6. Environmental impact assessment laws

b. Laws directed at land use control:

1. State land use and land use planning laws

2. Public lands laws controlling State-owned lands or submerged lands

3. Sediment or erosion control laws

4. Floodplain protection laws

5. Agricultural zoning laws

6. Local zoning enabling laws

7. Port district enabling laws

8. Other laws

States differ in the degree of regulatory constraint. Sixteen states were examined for their regulation of containment site real estate:

California	Maryland	North Carolina
Florida	Massachusetts	Oregon
Georgia	Michigan	Texas
Illinois	Mississippi	Virginia
Louisiana	New York	Washington
		Wisconsin

The greatest number of regulatory constraints existed in California, Massachusetts, and New York; the least number existed in Louisiana, Mississippi, and Texas.

It is reasonable to expect that the different characteristics of upland and inundated (i.e., intertidal or subtidal brackish, marine or fresh, or naturally inundated fresh water) sites will affect the ease with which they can be managed for aquaculture. Ultimately, it would be desirable to complete Table 1 or a modified, expanded version of it for each species being evaluated to determine its suitability to a particular project.

Stocking procedures using commercially acquired stocks would be similar in both types of sites. If a fully extensive cultivation operation were being considered and if natural recruits were locally available and legally exploitable, natural tidal flushing might be used to stock some sites. An upland site situated in the same vicinity would require pumps or other energy-subsidized stocking procedures. On the other hand, predator/competitor control and disease control would be simpler in an upland containment site.

Table 1

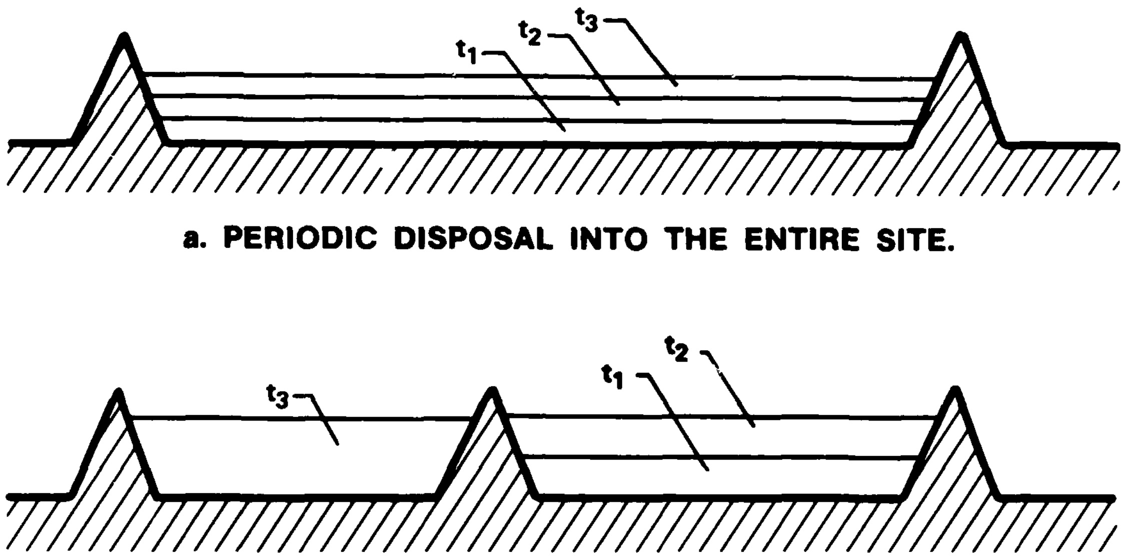
Species Evaluation

Activity	Recommendations: Upland Site	Recommendations: Inundated Site
Stocking		
Predator/competitor control		
Disease control		
Feeding		
Water quality management		
Contaminant management		
Harvesting		
Marketing		

Traditional drain, dry, and till techniques for destroying unwanted aquatic organisms could only be practiced upland. Mechanical techniques for predator and competitor elimination from inflowing water would also be easier to accomplish in an upland site. Feeding procedures would be comparable. Water quality control and contaminant-related problems would be less costly and less probable, respectively, in an inundated site. A regular schedule of inundation would provide a hydraulic energy subsidy to reduce pumping costs. The historical placement of chemically contaminated dredged material has been into upland sites so that the potential for a contaminant problem is less within inundated sites. Harvesting would employ different techniques in the two types of sites. Harvesting following a controlled drawdown might be the method of choice in an upland site while being impractical or impossible in a flooded area. Marketing the harvested crop would not be a site-specific consideration except as it would be related to the species selected and the locality's access to a market for that species.

There are at least two general concepts of disposal area management applicable to this discussion. Figure 1a depicts the placement of dredged material into the entire site. The dredged material would be distributed over the site according to the relative area within the site and the relative volume and physical characteristics of the material together with controlled disposal operation conditions like pipeline placement and movement. It is unlikely that culture operations could be sustained within a Figure 1a-configured site during active disposal, although it is not impossible. A small volume disposal event into a large site together with a species tolerant to suspended sediment describe one potential scenario. The length of time following a disposal event before cultivation activities could begin will be a site-specific variable depending on site size and configuration, material volume and character, and possible use of dredged material dewatering and other volume-reducing techniques used for efficient disposal area management. A site may be unavailable to aquaculture during the active

dewatering period. Otherwise, aquaculture and dewatering objectives are totally compatible. Figure 1b depicts a disposal area divided into multiple compartments as cells which would be filled sequentially over the life of the containment area.



a. PERIODIC DISPOSAL INTO THE ENTIRE SITE.

b. SCHEDULED DISPOSAL INTO SITE-CELLS.

t MAY BE A NUMBER BETWEEN SAY 1 AND 50
SPREAD OVER AS LONG AS 50 YEARS.

Figure 1. Disposal area management options for aquaculture

The construction of additional internal diking in a site produces a configuration with numerous advantages over an undivided area. The most obvious benefit would be related to the isolation of one or more cells from dredged material disposal for an extended period of time. A more or less continuous production schedule would thereby be possible in such a site even during dredged material disposal operations. This configuration has an additional benefit in a new site in that it isolates the aquaculture operation from potentially chemically contaminated material.

COSTS

a. What, if any, special site-specific procedures or construction or maintenance procedures would be practical to "optimize" containment site suitability?

b. How much would these special procedures cost?

c. Who would pay?

If the sponsor of the dredging project, say a city or local port authority or the Federal government, had to pay the bill, would the concept still be attractive? Would the added cost of site alteration for mariculture

be justified by benefits in the form of operational efficiency? Higher operational efficiency really means accomplishing the disposal of dredged material at relatively lower cost. If project sponsors or the Federal government had no difficulty locating containment site real estate and negotiating easements on that real estate to permit disposal of dredged material, the benefits of changing the current way of doing business would be questionable. But with the increasing difficulty of locating new containment site real estate, alternative disposal options such as ocean disposal become more attractive. These options involve higher material transportation costs between the dredging and disposal locations. The issues that would determine the sponsor's or government's willingness to pay for special locational, construction, or maintenance procedures that would make a containment site suitable for aquaculture would be cost issues. If the costs of these "special" procedures were less than or equal to the cost of an alternative disposal mode, the sponsor would probably be willing to pay; otherwise, the financial burden of special procedures might become the responsibility of the aquaculturist.

If the containment area landowner or aquaculturist had to pay the bill for extra site planning or construction or modified dredged material disposal operations, would sites still be attractive? The answer to this of course depends most simply on the aquaculturalist's net profit relative to potential profits possible from operations elsewhere. If a property owner or lessee wanted to use property for aquaculture and he had to pay for dike construction to make the site suitable for both dredged material disposal and aquaculture, there would be no incentive for him to permit dredged material disposal. He could venture into aquaculture without the inconvenience of integrating his activity with the dredging cycle. So the answer becomes very simple. If a landowner or land lessee can use land more profitably for aquaculture than for other purposes and if the sponsor or Federal government provides no economic incentive in the form of a construction subsidy or otherwise, the landowner may pursue his aquaculture options independently.

BENEFITS

What would make a containment site attractive to an aquaculturist? This question was initially considered in the above discussion concerning costs. Containment sites could become attractive to an aquaculturist who is not the landowner if they created an opportunity to obtain relatively inexpensive real estate located near sources of fresh, brackish, or saltwater essential to their business. If, by their basic design or with minor design alterations, a containment site could be used as a pond and thereby save pond construction costs, either the landowner or the land lessee would benefit.

What would make containment site aquaculture attractive to the Corps of Engineers? The development of any multiple-use option for a dredged material containment site that would make disposal site acreage more readily available would be the principal attraction. A multiple-use option such as aquaculture that could fit into a natural stock augmentation program to replenish animal resources reduced by pollution, overexploitation, or habitat destruction, and that would be compatible with a philosophy of environmental stewardship, would also be beneficial for the Corps of Engineers. The

positive public relations that would accompany the demonstration of a productive use of dredged material containment areas would be another incentive.

CONCLUSIONS

In anyone's final analysis, it is obvious that what I have done during this discussion of the applicability, costs, and benefits of mariculture or aquaculture in dredged material containment sites is to raise many questions and provide very shallow responses. If my questions stimulate discussion at this meeting and if that discussion leads to any conclusions, then I will feel I've achieved my goal.

AD P002131

OPERATING A MARICULTURE FACILITY IN A DREDGED MATERIAL CONTAINMENT SITE: THE LEGAL FRAMEWORK

by
Durwood M. Dugger and Michael A. Roegge
Commercial Shrimp Culture
International, Inc.
Los Fresnos, Texas 78566

Durwood M. Dugger

ABSTRACT

Aquaculture legal requirements are often unclear. State and Federal agencies are often unfamiliar with the operations of the aquaculture industry and misconceptions about the effect of such activities are common. It appears that obtaining permits for containment area acreage will be relatively straightforward as the areas are already considered "disturbed." In Texas, where the legal environment is less restrictive than in many states, three groups play a role in the permitting process: Federal agencies, State agencies, and local interest groups. Federal agencies include the Corps of Engineers, U. S. Fish and Wildlife Service, National Marine Fisheries Service, Environmental Protection Agency, and the Soil Conservation Service of the U. S. Department of Agriculture. Texas Parks and Wildlife and Texas Water Quality are two State agencies with permit requirements. Local interest groups are often very influential in the decision to grant various permits. The prospective culturist should carefully investigate which agencies require permits. At a minimum, a full site survey, project layout, details of water intakes and discharges, filters, and levee specifications will be required.

INTRODUCTION

There have been few operational, commercial facilities on any dredged material containment site and it is for this reason that the legalities involved in this type of development are somewhat hazy. Perhaps the best

way to approach this is by discussing the procedures involved in permitting sites adjacent to disposal areas and trying to meld the two.

The permitting process involved in the acquisition of coastal lands in Texas involves not only the U.S. Army Corps of Engineers but also several other major Federal and State agencies and a number of smaller commenting societies. While Texas has relatively few hurdles to overcome in comparison to other states, existing situations make it difficult to acquire permitting on coastal land.

Thousands of acres of low lying coastal land, including dredged material containment areas, are prime candidates for mariculture development. If these areas could be permitted and developed, a mariculture industry might evolve that would help in reducing the amount of dollars spent on imported seafood products.

In order for a mariculturist to maintain his sanity in the permitting process, it is best to treat it as a game. If you treat it seriously, it is all over before it starts, so let us look at it from a game standpoint, ice hockey for instance. The principals in our game are as follows:

a. The Mariculturist (CSCI) - "The Puck"

b. The Permitting Agencies - "The Players"

c. The Permit and Permitting Process - "The Game"

d. Establishment of the Mariculture Industry - "The Goal"

CSCI - "THE PUCK"

To give you a little bit of my personal background, I am the president of Commercial Shrimp Culture International (CSCI), which is involved in the commercial development of shrimp culture around the world. I have been growing and cultivating aquatic organisms since I was about 12 years old. I started in college working with shrimp in 1968 and began my commercial career with Ralston Purina at their Crystal River Mariculture Center in 1972.

The Purina Crystal River site was on a dredged material containment area; however, there was no special attention directed towards its location other than its conjunction with the local power plant. It was not an ideal site because of the soil type, but we were successful in growing fair quantities of shrimp and probably led the commercial sector in the technology for growing marine shrimp. Since that time I have worked with Sun Oil Company and CSCI, the latter has consulted for a number of major U.S. corporations. Perhaps, at this time, I should also qualify my own outlook and position in regards to the environment. It may not sound like it at times, but I am a conservationist; however, I do believe that conservation is the wise use of resources, not a closeting of the same.

CSCI now operates a freshwater shrimp project near Brownsville, Tex.; a total area of 104 acres with 75 acres of water surface. This project was not built on a dredged material containment area but CSCI has had a considerable amount of experience dealing with the permitting agencies involved in mariculture (particularly Texas) in dredged material containment sites.

CSCI has recently leased and acquired permits to use a 124-acre containment area on the Brownsville Navigation District ship channel (Figure 1). We have not yet started construction at this site so I cannot really tell you about operating on that particular containment site. I can, however, tell you what is involved in getting permits for sites like it and for sites that are not containment sites.

Figure 1. Aerial view of the containment area leased by CSCI for aquaculture. The area lies northwest of the playa (dark area, lower right center of photo). Perimeter levees extend from the playa north to the Brownsville Ship Channel and northwest to another playa adjacent to the channel. Additional levees along the base of the playas and the ship channel enclose the area

This is the layout of the area that we are working in (Figure 2). The ship channel is to the left. The center area is a single cell of 124 acres. This area has been transferred from the Corps' active disposal sites to an inactive status and, as it is planned now, no further material will be deposited on the site.

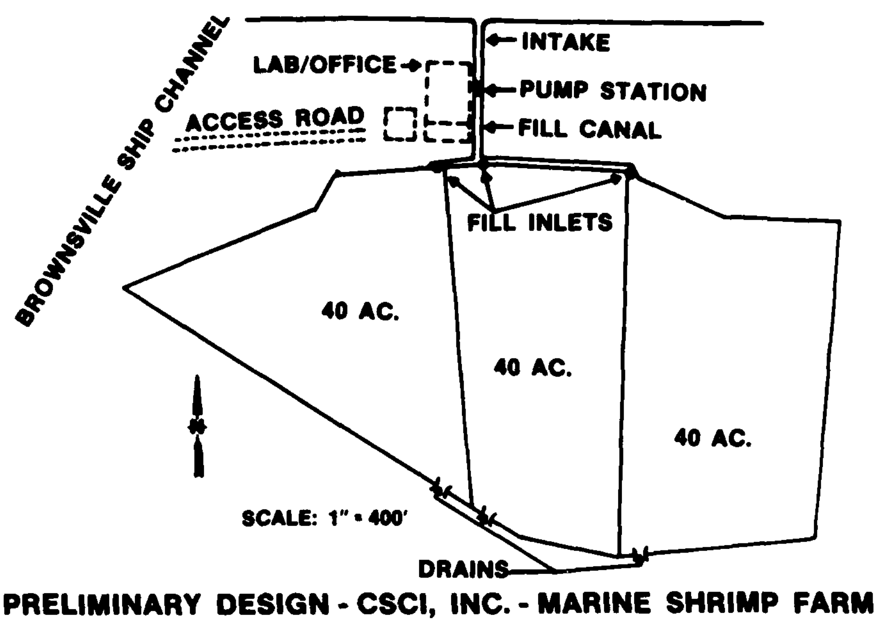


Figure 2. Site layout

PERMITTING AGENCIES - "THE PLAYERS"

In any game you must have a referee who, for our purpose, will be the U.S. Army Corps of Engineers. At this time I would like to state that from the beginning they have been fair with us and to some extent have even taken our side in our permitting processes. I really do not have any complaints with the Corps of Engineers itself.

The players in the permitting game are as follows:

a. Texas Parks and Wildlife Department (TP&W)

b. U.S. Fish and Wildlife Service (USFWS)

c. National Marine Fisheries Service (NMFS)

d. Texas Water Quality Commission

e. USDA Soil Conservation Service (SCS)

f. Environmental Protection Agency (EPA)

The Texas Parks and Wildlife Department is probably the first group that will review the permit. If you are working with exotic species, you will have to apply for an exotic species permit. Approval will be based on your site location and on your ability to maintain or contain the exotic species. The TP&W is concerned primarily with game fish because it is the

sport fishermen who pay their bills through fishing and hunting licenses. We have found the TP&W to be a relatively reasonable group and, if you present a logical argument to them, will normally respond in a rational manner.

Normally there is a Federal counterpart to most of the State agencies. As you saw from a previous presentation, Texas has comparatively few constraints in the permitting process. Since we have not applied for permits in other states, I really cannot comment on their processes. Even in Texas' relatively unrestrained atmosphere, however, there have been more than enough regulatory agencies for us to contend with.

The next player is the U.S. Fish and Wildlife Service who we have found to be by far the most unreasonable, illogical group that we have dealt with. By divine right, the U.S. Fish and Wildlife Service claims that all land with an elevation of less than five feet above mean high tide is within their domain. Two feet above mean high tide is holy ground on which no one may trespass. Their prime interest, again, like the Texas Parks and Wildlife Department, is the fish and game business; fishing and hunting licenses also support them. There seems to be a policy within this agency to stop mariculture development in the coastal zone at all costs and they have even gone so far as to tell us that we were "not a water-dependent industry." I have yet to figure out how they arrived at that conclusion.

The National Marine Fisheries Service has been responsible for developing a lot of the technology that is being used in marine shrimp culture. They are also one of the agencies that review permit applications. We found them to be, for the most part, behind and in the shadow of the U.S. Fish and Wildlife Service. They did have particular interest in our intake systems, the amount of water and the velocities that the water was picked up at, primarily because of the entrainment of larval marine forms. This particular problem was relatively easy to get around by way of a system designed by CSCI that returns the larval forms to the environment unharmed.

Another player is the Texas Water Quality Commission. Their prime interest is groundwater pollution and saltwater intrusion into the groundwater resources. They were also concerned for some reason about the amount of water that we would be pumping from the Gulf of Mexico. Most coastal sites, at least in south Texas, do not have to worry about groundwater intrusion because there is not any fresh groundwater within many miles of the coast. Texas Water Quality is also interested in discharges, particularly if you are discharging into any of the estuarine systems. The Federal counterpart to the Texas Water Quality Commission is, of course, the EPA. They are particularly interested in the discharge quality, principally suspended solids and nitrogenous waste.

The final agency that we deal with, and the ones most probably responsible for a lot of the success that we have had, is the U.S. Soil Conservation Service. They have provided a considerable amount of engineering expertise to us in levee construction and have advised us on things that are particularly suitable to our exact site, with which professional engineering firms (of which we have very few of in south Texas) are not at all familiar.

The above agencies are the varsity players in the permitting game but there is also a junior varsity league that can be just as important and they are as follows:

First there is the Texas Historical Society. Friends, we have had dinosaurs, bears, alligators, and Indians depositing debris all over south Texas and I do not care where you put a stick down, you are going to find something that someone will deem to have some historical value.

The Audubon Society, a lesser player in the permitting game, is a well-meaning group but not always technically well advised. Aquaculture, and shrimp culture in particular, generally promotes the enhancement of bird populations. I should point out that, in the former cow pasture in which we now operate our freshwater shrimp farm, we have 26 species of wetland birds that were not there before our development. Probably the worst thing about the Audubon Society is that they have a lot of very sincere people but without much technical expertise. They tend to get overly concerned with things that they really do not have an understanding of, such as habitat productivity.

The Sierra Club is next. We did not have any problems with the Sierra Club. It happens that the Brownsville Navigation District's port engineer is president of the local Sierra Club Chapter. I understand that in some areas that they are concerned with all forms of wildlife that might be threatened or endangered with industrialization and with the loss of habitat.

Finally, is the Gulf Coast Conservation Society. We found that with them we could offer an even trade-off. These people are concerned with the sport fisheries since most of them are sport fishermen. We simply told them that we would be producing bait shrimp in the off-season. That resolved that problem.

THE PERMIT AND THE PERMITTING PROCESS - "THE GAME"

The game itself is one of the puck being passed from one player to another and hoping that enough data have been collected justifying approval of the permit so that a shot can be made on the goal: movement towards self-sufficiency in the production of seafood products.

Here again, one of the major problems that we have had is with the permitting process and lack of familiarity that these agencies have with the newly emerging mariculture industry and the environmental impact that industry has. We have tried to document the fact that the mariculture site is not necessarily detrimental to wildlife. The interesting thing about this is that a nest is by our access road that we use about 40 or 50 times a day. We have had birds nesting on our levees, and have had to mark their nests so that our feeding trucks would not run over them. From what we can tell, our presence is having no detrimental effect on bird populations; rather the contrary is true.

When you permit a containment area, which we have done, you notice some interesting differences between permitting a site that is not a dredged material containment site and other coastal land. In our case, we spent two years and between $20,000 and $40,000 trying to permit a salt flat that was immediately adjacent to the containment site that we now have permits for. As a result of several hurricanes, the levee separating the containment cell from this other tract of land had been damaged and dredged material has covered a large percent of this rich nursery area. Nevertheless, we never

did get the permits for this land. It was two feet above mean high tide and about two miles from the high tide point. In the review process we were assured that trout and redfish spawn on this dry ground. Two years has passed with continual effort on our part and we never have gotten the permits. We applied for a permit in a dredged material containment site; we had it in less than two months, and it had gone by all of the agencies. This was primarily because the land was already considered di ırbed.

If you are going to obtain a permit for a site, I can offer a few possible strategies for "the game":

a. Site

Get a survey on the site with a 50-100' grid, whether it is on dredged material or not. Determine its elevations. This will have a lot to do with the other agencies comments. The closer to inundation you are, the less likely you are to get the full agreement of the agencies commenting on the permits.

b. Project Layout

You will have to supply the Corps application with cross sections of your levees, detailing their widths. You should show your levee layout, preferably on a topographical map. You will have to pinpoint your intake and discharge locations.

c. Intake

Show in detail the intake structure. You will have to give the specifications on your intake system, including gallons per minute and feet per second pumped.

d. Filtration

You must detail the filtration method that you are going to use to remove the water-borne predators. It should be one that returns any larval forms back from where they came, unharmed.

e. Discharge

Show in detail the discharge structure. Detail the amount that you discharge and the types of chemical wastes and imbalances produced. Concerning the quality of the discharge, you will find that saltwater sites tend to produce foam, just like they do at the beach. Foam is not permissible after it goes through the mariculture project whether it is of natural origin or not. It must be dealt with in the discharge design.

A copy of our permit and a number of the documents that we have submitted are included in the Appendix.

Finally, let me discuss our experience in dealing with a public entity in acquiring land. We have negotiated a contract with the Brownsville Navigation District. They control about 43,000 acres of coastal land. If possible, you would want to purchase the land. That is usually not the case in dredged material containment areas. If you are dealing with a public agency, you might try to bargain with them so that for your first few years you pay nothing for the land because you are at risk at that point and they might as well share some of your risk. They are probably not using the land anyway, if it is a containment site, unless it is an active disposal area. You

should negotiate for as long a term of lease as you can, 25 to 50 years if you plan to be around for awhile. We do. You should attempt to finalize all of your contracts, even if you have not yet obtained all necessary permits, being certain that contracts are contingent upon successful permit activities.

CONCLUSIONS

In conclusion, I think that aquaculture, or mariculture, in dredged material containment areas is a wise use of one of our land resources. I am really disturbed, however, by the point that I discussed earlier: it took two months to get permits on a containment area and two years for a similar adjacent site that was judged to be environmentally sensitive by certified and unbiased professionals. I agree that our resources must be conserved, but they must also serve man as well.

Equador is where all shrimp mariculturists point when they want to show the success of their industry. There are now over 120,000 acres of shrimp ponds in Equador and the National Marine Fisheries Service reported about 30 million pounds of farmed shrimp produced by the Equadorian operations in 1980. The ponds are very unsophisticated and look a lot like containment areas.

If we are going to have a mariculture industry in the United States, it is going to have to have land on which to develop. If we are denied coastal lands and practical access to the waters' edge, it is going to be the legal and moral equivalent of taking our terrestrial farmers and telling them that they can farm only mountaintops and deserts.

Last year, $1 billion of the U.S. economy went out just to purchase foreign-produced shrimp and about $200 million of that was for maricultured shrimp. There is no reason why this money should not stay in the United States. The technology to produce this shrimp was developed in the United States and is the same that is being used successfully in Equador because we as consultants take it down there to sell.

The "game" analogy that I have used in my discussion is something like ice hockey and is a considerably chilling experience. The groups that I have described involve the Corps as the referee, the permitting agencies as players, the mariculturist as the puck, and the goal as the establishment of the mariculture industry itself. This goal is aimed at reducing the importation of large quantities of seafood items. The problem, however, lies in getting all of the players on the team to stop the game delay tactics and start to function as a cohesive unit in order to get the puck in the net and score the winning goal.

QUESTIONS AND ANSWERS

Roger Mann (Wood's Hole): It is going to very difficlut to use introduced species in mariculture if they are not already in use here, simply because the precautionary introduction program takes so long to get through. Certainly for those of you who are interested in growing exotic species, that is going to set you back another three to five years. Also, if you look at

some of the New England states and their discharge programs for seawater systems, it is impossible to get dissolved oxygen up as high as the Massachusetts State authorities want. You cannot explain that to these people when you take down a bucket of seawater and say 'hey, I just cannot get that much oxygen into this because it is already saturated.' So there are some real problems with state legislation as well.

Bill Trimble (St. Martin and Iberville Land Company): We have been going through the permitting process also. I am a little more familiar with how to do this because I was with State and Federal agencies for quite a while. And I would like to pass on a way that will eventually get a permit. It took us approximately 16 months to get our last permit to grow crawfish in a wetland area that had been in that type of culture for about 17 years. The procedure that did work after the 16 months was going to the Corps' Office in New Orleans and telling them that I was not going to leave that office until we resolved the problem. This is about the most effective way, and I think that we have to realize that these agencies are burdened with a lot of paperwork that those of us in industry do not appreciate or have time for. To alleviate this problem, I would like your thoughts on this: some of the larger companies have staffs that do only permitting work. It is very time-consuming, and in fact it has inhibited my work, although we are very conscientiously associated with conservation. You just do not have the time to do that and your competitors often do not do it. Would you agree with me that, for the first permit involving the use of a containment area, the Corps of Engineers should walk that paper through for the individual. Not the second one or the third one or the fourth one. But there is just so much to learn and you absolutely do not have shutdown time to do that. And the second suggestion is that the Corps or some other agency take a leading role in getting the other agencies organized and cooperating among themselves and mariculturists.

Paul Carangelo (Island Botanics): You worked in the area and you had to go for the permits and you now have the site. How long, not getting into your own economics, does that site have to be operational for you to break even. What is the time between containment site development and the loading schedule for a dredge operation. How long do you have to be in operation to break even?

Mr. Dugger: That will probably vary from site to site. I think we are probably looking at 2 or 3 years on the site. In our definition, 124 acres is not enough to justify commercialization. If we did not have in mind getting considerably larger than that in that area, we would not be there. There is the possibility there will be another 500 acres available.

APPENDIX

1. Texas Shellfish Culturists License.
2. Texas Parks and Wildlife Department Exotic Shellfish Permit and Amendments.
3. Corps of Engineers Permit.

304 - 105268 10-7-80

STATE OF TEXAS	SHELLFISH CULTURIST'S LICENSE	Fee: $25.00	069

OWNER OR MANAGER'S NAME Commercial Shrimp Culture Intl.	ADDRESS P. O. Box AK	
CITY Port Isabel	STATE Texas	ZIP CODE 78578
BUSINESS ADDRESS P.O. Box AK	CITY Port Isabel	COUNTY LOCATED IN Cameron

Signature of Licensee

NOTICE

EXPIRES AUGUST 31, 1981

VALID ON SEPT. 1st OR ISSUE DATE, WHICHEVER IS LATER

NON-REFUNDABLE

THIS CERTIFIES THAT the licensee, HAVING PAID the license fee is hereby privileged to engage in the business of production, propagation, transportation, possession or sale of shellfish raised in private ponds or reservoirs at the Business Address indicated above.

Issued at Austin, Texas,
October 9, 1980 Time of Issuance 4:00 ☐ AM ☒ PM

PARKS AND WILDLIFE DEPARTMENT

Issued by [signature]
Deputy, County Clerk, Warden

TEXAS
PARKS AND WILDLIFE DEPARTMENT

CHARLES D. TRAVIS
EXECUTIVE DIRECTOR

4200 Smith School Road
Austin, Texas 78744

October 4, 1982

Mr. Durwood M. Dugger, President
Commercial Shrimp Culture International
Post Office Box AK
Port Isabel, Texas 78578

Dear Mr. Dugger:

Enclosed is your Exotic Shellfish Permit for State Fiscal Year 1982-83. Please note that the provisions of this permit have been changed to reflect that it is a "General" Permit. Each new shipment of exotic shellfish will now be treated as an Amendment to the General Permit. To obtain an Amendment, it will be necessary for you to forward a copy of the appropriate forms to reflect an examination for disease and to specify the source of the exotic shellfish. When these forms are received, an amendment will be issued to your General Permit to reflect the new shipment of certified exotic shellfish.

Enclosed are forms for your use in connection with subsequent shipments of exotic shellfish imported into Texas. The Declaration of Source establishes the source, species and destination of the exotic shellfish and the Certificate will document that the shellfish involved are free of disease. If the exotic shellfish were cultured in this country, a signed statement from the source hatchery that the shellfish have been cultured in the hatchery without detection of disease may be used in lieu of the Declaration of Source and the certificate forms.

As this letter suggests, we are currently re-evaluating our permitting program and welcome your suggestions on how to best serve you and the public. The exotic shellfish program has been transferred to our Resource Protection Branch. We therefore request that you forward correspondence concerning your permit to the Permit Section, Resource Protection Branch, 4200 Smith School Road, Austin, Texas 78744. The telephone number for this branch is Area Code 512/479-4864.

Sincerely,

Robert J. Kemp

Robert J. Kemp
Director of Fisheries

RJK:GCA:F286:cf

Enclosures

TEXAS PARKS AND WILDLIFE DEPARTMENT
GENERAL EXOTIC SHELLFISH CULTURE PERMIT NO. 2, 1982-83

The Permittee, Durwood M. Dugger, President, Commercial Shrimp Culture International, P.O. Box AK, Port Isabel, Texas 78578 is authorized to import, transport, possess and propagate the following exotic shellfish species:

(*Penaeus vannamei*)
(*Penaeus stylirostris*)
(*Macrobrachium rosenbergii*)

In order to assure that the exotic shellfish are free of disease, this permit is valid only under one of the following conditions:

1. That permittee obtain a certificate from a shellfish disease specialist, approved by the Department, to certify that each shipment of exotic shellfish stock imported from outside the United States, has been examined and found free of disease. A copy of this certificate will be forwarded to the Department and an amendment to this Permit will be issued to reflect the updated status of the exotic shellfish possessed by permittee.

2. If the exotic shellfish stock originates from within the United States, it will have been examined and found free of disease as specified at paragraph 1 above or a statement from the source hatchery that the shellfish have been cultured in the hatchery without detection of disease will be provided to the Department.

3. Permittee will retain any new shipment of exotic shellfish under controlled conditions until the amendment to the General Permit has been received to certify that the additional stock is free of disease and approved for general introduction to permittee's facilities.

The exotic shellfish authorized by this permit will be cultured at the following location under supervision of the individual listed below:

Location:	Shrimp Culture International Monroe Street Port Isabel, Texas 78578
Supervised by:	Durwood M. Dugger

In the event of overflow or flooding of the ponds or tanks containing these exotic species or release of the animals appears imminent because of tropical storm or any other reason, the permittee is directed to destroy these animals to prevent their release into public waters. It is the responsibility of the permittee to have on hand a sufficient quantity of Baytex or a similar biocide to destroy all shellfish in danger of release.

This permit is issued by authority of Chapter 51, Parks and Wildlife Code. The expiration date of this permit is August 31, 1983.

Robert J. Kemp

Robert J. Kemp
Director of Fisheries

RJK:GCA:cf

DECLARATION OF SOURCE
(To be completed by Importer or Agent)

CONSIGNMENT NO: ______________________
(your number)
Date received: ______________________

1. Name and address of Importer: Telephone number: ____________

____

____

____

2. Type of establishment of destination:

(a) University or College _____ (c) State or Local Agency _____
(b) Federal Agency _____ (d) Commercial Firm _____
(e) Other ______________________________________

3. Name and address of Exporter:

____

____

____

4. Type of establishment of origin:

(a) University or College _____ (c) State or Local Agency _____
(b) Federal Agency _____ (d) Commercial Firm _____
(e) Other ______________________________________

5. Country of origin or export: ______________________________

6. Species and numbers of shellfish in consignment:

SPECIES:	LARVAE:	JUVENILE	ADULT

I hereby certify that the information contained in this declaration is true and accurate.

Forward copies to:

1. Texas Parks and Wildlife Department
Resource Protection Branch
4200 Smith School Road
Austin, TX 78744

____
Signature (importer or agent)

2. Certifying Officer

Date: ______________________

TEXAS PARKS AND WILDLIFE DEPARTMENT
EXOTIC SHELLFISH DISEASE INSPECTION CERTIFICATE
(To Be Completed By Certifying Officer)

I HEREBY CERTIFY THAT:

A subsample of shrimp, consignment number __________ dated ____________, was examined by me and was given routine examination according to "guidelines for the examination of disease agents in marine and freshwater shrimp"[1/] and the following biological disease agents were not found. (If a box is not checked, give names of agents present to the right of the box).

1. Baculovirus ☐
2. Abundance of bacterial lesions or bacterial presence in circulatory systems ☐
3. Microsporidia ☐
4. Gregarine ☐
5. Other internal protozoa ☐
6. Dense epibiont presence ☐
7. Trematode ☐
8. Cestode ☐
9. Nematode ☐

FOR INFORMATION PURPOSES ONLY:

Additional examinations were conducted and the following results were obtained (use back of sheet if needed):

______________________ Certifying Officer

______________________ Signature: Certifying Officer

______________________ Title

______________________ Place of issuance

______________________ Date

[1/] Unnumbered publication available from Extension Fish Disease Diagnostic Laboratory, Texas A&M University, College Station, Texas.

TEXAS
PARKS AND WILDLIFE DEPARTMENT

CHARLES D. TRAVIS
EXECUTIVE DIRECTOR

4200 Smith School Road
Austin, Texas 78744

October 22, 1982

Mr. Michael A. Roegge
Commercial Shrimp Culture International
P.O. Box C
Los Fresnos, Texas 78566

Dear Mr. Roegge:

Enclosed is Amendment Number I to your General Exotic Shellfish Culture Permit Number 2 1982-83 to indicate the change of address as requested by your letter of October 18, 1982.

Thank you for your letter and for your cooperation with the Department.

Sincerely,

George C. Adams

George C. Adams
Permit Section
Resource Protection Branch

GCA:pb

Enclosure

Celebrating One Hundred and Fifty Years – 1836 - 1986

Amendment Number I

General Exotic Shellfish Culture Permit Number 2 1982-83

October 22, 1982

General Exotic Shellfish Culture Permit Number 2 1982-83 issued to Durwood M. Dugger, President, Commercial Shrimp Culture International, P.O. Box AK, Port Isabel, Texas 78578 is hereby amended to reflect the following change of address: Commercial Shrimp Culture International, Line H. Road, P.O. Box C. Los Fresnos, Texas 78566.

All other provisions of this permit remain the same.

Robert J. Kemp

Robert J. Kemp
Director of Fisheries

Application No. 16031

Name of Applicant Brownsville Navigation District

Effective Date 01 JUL 1982

Expiration Date (If applicable)

DEPARTMENT OF THE ARMY
PERMIT

Referring to written request dated 1 March 1982 for a permit to:

(X) Perform work in or affecting navigable waters of the United States, upon the recommendation of the Chief of Engineers, pursuant to Section 10 of the Rivers and Harbors Act of March 3, 1899 (33 U.S.C. 403);

(X) Discharge dredged or fill material into waters of the United States upon the issuance of a permit from the Secretary of the Army acting through the Chief of Engineers pursuant to Section 404 of the Federal Water Pollution Control Act (86 Stat. 816, P.L. 92-500);

( ) Transport dredged material for the purpose of dumping it into ocean waters upon the issuance of a permit from the Secretary of the Army acting through the Chief of Engineers pursuant to Section 103 of the Marine Protection, Research and Sanctuaries Act of 1972 (86 Stat. 1052, P.L. 92-532);

Brownsville Navigation District
P.O. Box 3070
Brownsville, Texas 78520

is hereby authorized by the Secretary of the Army:

to construct a channel and intake pump for a shrimp farm

in the Brownsville Ship Channel

at Corps of Engineers Station 34+000 approximately 10 miles southeast from Brownsville, Texas

in accordance with the plans and drawings attached hereto which are incorporated in and made a part of this permit (on drawings: give file number or other definite identification marks.) in four sheets, sheet one of which is entitled "PROPOSED PUMP INTAKE STRUCTURE AND CHANNEL,"

subject to the following conditions:

I. General Conditions:

a. That all activities identified and authorized herein shall be consistent with the terms and conditions of this permit; and that any activities not specifically identified and authorized herein shall constitute a violation of the terms and conditions of this permit which may result in the modification, suspension or revocation of this permit, in whole or in part, as set forth more specifically in General Conditions j or k hereto, and in the institution of such legal proceedings as the United States Government may consider appropriate, whether or not this permit has been previously modified, suspended or revoked in whole or in part.

ENG FORM 1 JUL 77 1721 EDITION OF 1 APR 74 IS OBSOLETE. (ER 1145-2-303)

b. That all activities authorized herein shall, if they involve, during their construction or operation, any discharge of pollutants into waters of the United States or ocean waters, be at all times consistent with applicable water quality standards, effluent limitations and standards of performance, prohibitions, pretreatment standards and management practices established pursuant to the Federal Water Pollution Control Act of 1972 (P.L. 92-500, 86 Stat. 816), the Marine Protection, Research and Sanctuaries Act of 1972 (P.L. 92-532, 86 Stat. 1052), or pursuant to applicable State and local law.

c. That when the activity authorized herein involves a discharge during its construction or operation, of any pollutant (including dredged or fill material), into waters of the United States, the authorized activity shall, if applicable water quality standards are revised or modified during the term of this permit, be modified, if necessary, to conform with such revised or modified water quality standards within 6 months of the effective date of any revision or modification of water quality standards, or as directed by an implementation plan contained in such revised or modified standards, or within such longer period of time as the District Engineer, in consultation with the Regional Administrator of the Environmental Protection Agency, may determine to be reasonable under the circumstances.

d. That the discharge will not destroy a threatened or endangered species as identified under the Endangered Species Act, or endanger the critical habitat of such species.

e. That the permittee agrees to make every reasonable effort to prosecute the construction or operation of the work authorized herein in a manner so as to minimize any adverse impact on fish, wildlife, and natural environmental values.

f. That the permittee agrees that he will prosecute the construction or work authorized herein in a manner so as to minimize any degradation of water quality.

g. That the permittee shall permit the District Engineer or his authorized representative(s) or designee(s) to make periodic inspections at any time deemed necessary in order to assure that the activity being performed under authority of this permit is in accordance with the terms and conditions prescribed herein.

h. That the permittee shall maintain the structure or work authorized herein in good condition and in accordance with the plans and drawings attached hereto.

i. That this permit does not convey any property rights, either in real estate or material, or any exclusive privileges; and that it does not authorize any injury to property or invasion of rights or any infringement of Federal, State, or local laws or regulations nor does it obviate the requirement to obtain State or local assent required by law for the activity authorized herein.

j. That this permit may be summarily suspended, in whole or in part, upon a finding by the District Engineer that immediate suspension of the activity authorized herein would be in the general public interest. Such suspension shall be effective upon receipt by the permittee of a written notice thereof which shall indicate (1) the extent of the suspension, (2) the reasons for this action, and (3) any corrective or preventative measures to be taken by the permittee which are deemed necessary by the District Engineer to abate imminent hazards to the general public interest. The permittee shall take immediate action to comply with the provisions of this notice. Within ten days following receipt of this notice of suspension, the permittee may request a hearing in order to present information relevant to a decision as to whether his permit should be reinstated, modified or revoked. If a hearing is requested, it shall be conducted pursuant to procedures prescribed by the Chief of Engineers. After completion of the hearing, or within a reasonable time after issuance of the suspension notice to the permittee if no hearing is requested, the permit will either be reinstated, modified or revoked.

k. That this permit may be either modified, suspended or revoked in whole or in part if the Secretary of the Army or his authorized representative determines that there has been a violation of any of the terms or conditions of this permit or that such action would otherwise be in the public interest. Any such modification, suspension, or revocation shall become effective 30 days after receipt by the permittee of written notice of such action which shall specify the facts or conduct warranting same unless (1) within the 30-day period the permittee is able to satisfactorily demonstrate that (a) the alleged violation of the terms and the conditions of this permit did not, in fact, occur or (b) the alleged violation was accidental, and the permittee has been operating in compliance with the terms and conditions of the permit and is able to provide satisfactory assurances that future operations shall be in full compliance with the terms and conditions of this permit; or (2) within the aforesaid 30-day period, the permittee requests that a public hearing be held to present oral and written evidence concerning the proposed modification, suspension or revocation. The conduct of this hearing and the procedures for making a final decision either to modify, suspend or revoke this permit in whole or in part shall be pursuant to procedures prescribed by the Chief of Engineers.

l. That in issuing this permit, the Government has relied on the information and data which the permittee has provided in connection with his permit application. If, subsequent to the issuance of this permit, such information and data prove to be false, incomplete or inaccurate, this permit may be modified, suspended or revoked, in whole or in part, and/or the Government may, in addition, institute appropriate legal proceedings.

m. That any modification, suspension, or revocation of this permit shall not be the basis for any claim for damages against the United States.

n. That the permittee shall notify the District Engineer at what time the activity authorized herein will be commenced, as far in advance of the time of commencement as the District Engineer may specify, and of any suspension of work, if for a period of more than one week, resumption of work and its completion.

o. That if the activity authorized herein is not started on or before [illegible] day of July, 19 85, (one year from the date of issuance of this permit unless otherwise specified) and is not completed on or before thirty-first day of December, 19 85, (three years from the date of issuance of this permit unless otherwise specified) this permit, if not previously revoked or specifically extended, shall automatically expire.

p. That this permit does not authorize or approve the construction of particular structures, the authorization or approval of which may require authorization by the Congress or other agencies of the Federal Government.

q. That if and when the permittee desires to abandon the activity authorized herein, unless such abandonment is part of a transfer procedure by which the permittee is transferring his interests herein to a third party pursuant to General Condition t hereof, he must restore the area to a condition satisfactory to the District Engineer.

r. That if the recording of this permit is possible under applicable State or local law, the permittee shall take such action as may be necessary to record this permit with the Register of Deeds or other appropriate official charged with the responsibility for maintaining records of title to and interests in real property.

s. That there shall be no unreasonable interference with navigation by the existence or use of the activity authorized herein.

t. That this permit may not be transferred to a third party without prior written notice to the District Engineer, either by the transferee's written agreement to comply with all terms and conditions of this permit or by the transferee subscribing to this permit in the space provided below and thereby agreeing to comply with all terms and conditions of this permit. In addition, if the permittee transfers the interests authorized herein by conveyance of realty, the deed shall reference this permit and the terms and conditions specified herein and this permit shall be recorded along with the deed with the Register of Deeds or other appropriate official.

II. Special Conditions: (Here list conditions relating specifically to the proposed structure or work authorized by this permit):

a. That if the permittee, during prosecution of the work authorized herein, encounters a previously unidentified archeological or other cultural resource that might be eligible for listing in the National Register of Historic Places, he shall immediately notify the District Engineer.

b. That the Corps of Engineers spillbox lost by the construction of the shrimp farm be replaced at a location to be designated by the Brownsville Area Office.

The following Special Conditions will be applicable when appropriate:

STRUCTURES IN OR AFFECTING NAVIGABLE WATERS OF THE UNITED STATES:

a. That this permit does not authorize the interference with any existing or proposed Federal project and that the permittee shall not be entitled to compensation for damage or injury to the structures or work authorized herein which may be caused by or result from existing or future operations undertaken by the United States in the public interest.

b. That no attempt shall be made by the permittee to prevent the full and free use by the public of all navigable waters at or adjacent to the activity authorized by this permit.

c. That if the display of lights and signals on any structure or work authorized herein is not otherwise provided for by law, such lights and signals as may be prescribed by the United States Coast Guard shall be installed and maintained by and at the expense of the permittee.

d. That the permittee, upon receipt of a notice of revocation of this permit or upon its expiration before completion of the authorized structure or work, shall, without expense to the United States and in such time and manner as the Secretary of the Army or his authorized representative may direct, restore the waterway to its former conditions. If the permittee fails to comply with the direction of the Secretary of the Army or his authorized representative, the Secretary or his designee may restore the waterway to its former condition, by contract or otherwise, and recover the cost thereof from the permittee.

e. Structures for Small Boats: That permittee hereby recognizes the possibility that the structure permitted herein may be subject to damage by wave wash from passing vessels. The issuance of this permit does not relieve the permittee from taking all proper steps to insure the integrity of the structure permitted herein and the safety of boats moored thereto from damage by wave wash and the permittee shall not hold the United States liable for any such damage.

MAINTENANCE DREDGING:

a. That when the work authorized herein includes periodic maintenance dredging, it may be performed under this permit for 3 years from the date of issuance of this permit (ten years unless otherwise indicated);

b. That the permittee will advise the District Engineer in writing at least two weeks before he intends to undertake any maintenance dredging.

DISCHARGES OF DREDGED OR FILL MATERIAL INTO WATERS OF THE UNITED STATES:

a. That the discharge will be carried out in conformity with the goals and objectives of the EPA Guidelines established pursuant to Section 404(b) of the FWPCA and published in 40 CFR 230;

b. That the discharge will consist of suitable material free from toxic pollutants in other than trace quantities;

c. That the fill created by the discharge will be properly maintained to prevent erosion and other non-point sources of pollution; and

d. That the discharge will not occur in a component of the National Wild and Scenic River System or in a component of a State wild and scenic river system.

DUMPING OF DREDGED MATERIAL INTO OCEAN WATERS:

a. That the dumping will be carried out in conformity with the goals, objectives, and requirements of the EPA criteria established pursuant to Section 102 of the Marine Protection, Research and Sanctuaries Act of 1972, published in 40 CFR 220-228.

b. That the permittee shall place a copy of this permit in a conspicuous place in the vessel to be used for the transportation and/or dumping of the dredged material as authorized herein.

This permit shall become effective on the date of the District Engineer's signature.

Permittee hereby accepts and agrees to comply with the terms and conditions of this permit.

Eric S. Lang — 6-28-82

PERMITTEE — DATE

BROWNSVILLE NAVIGATION DISTRICT

BY AUTHORITY OF THE SECRETARY OF THE ARMY:

Marcos De La Rosa — 01 JUL 1982

MARCOS DE LA ROSA — DATE

Chief, Regulatory Branch

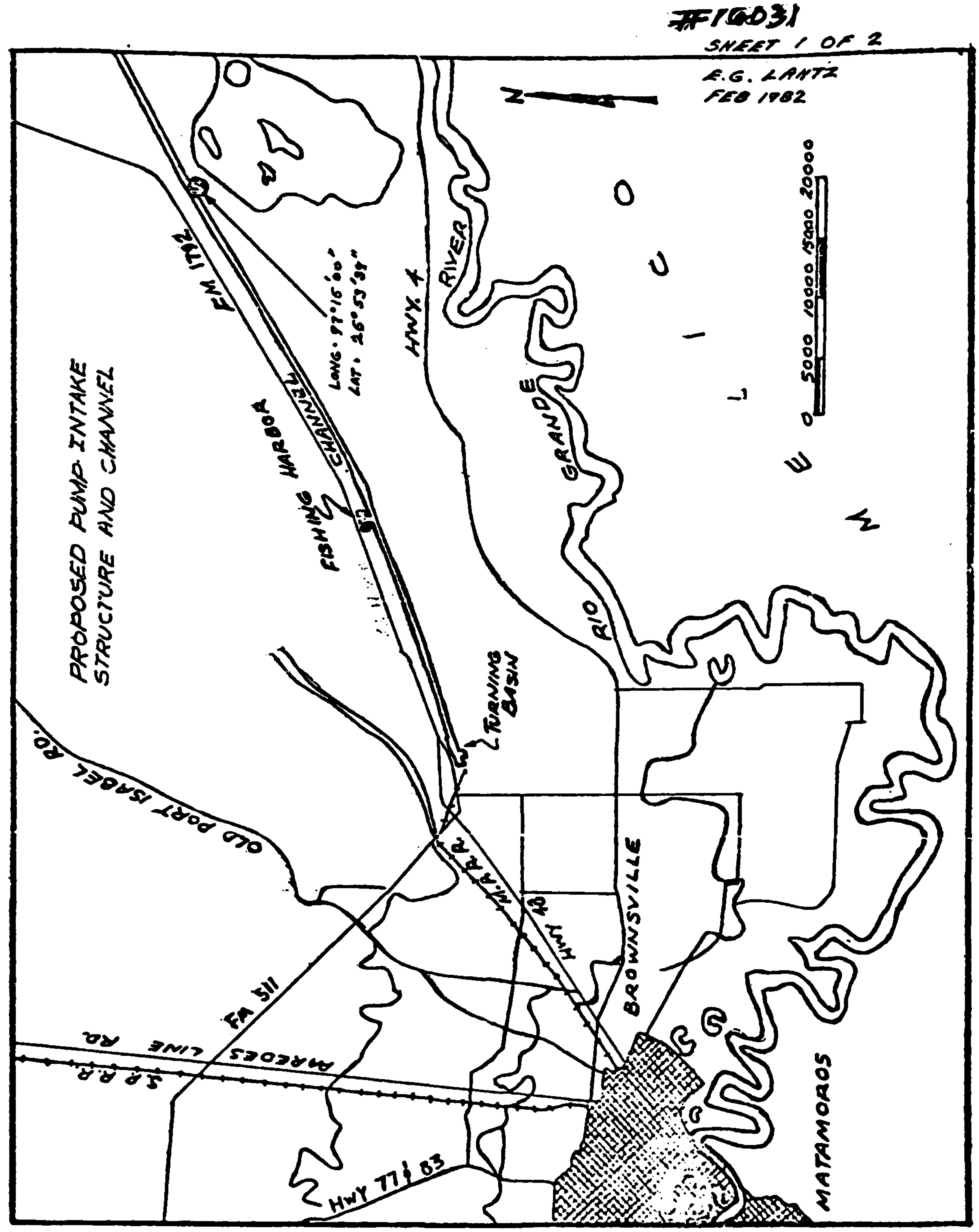
FOR THE DISTRICT ENGINEER,

U.S. ARMY, CORPS OF ENGINEERS

Transferee hereby agrees to comply with the terms and conditions of this permit.

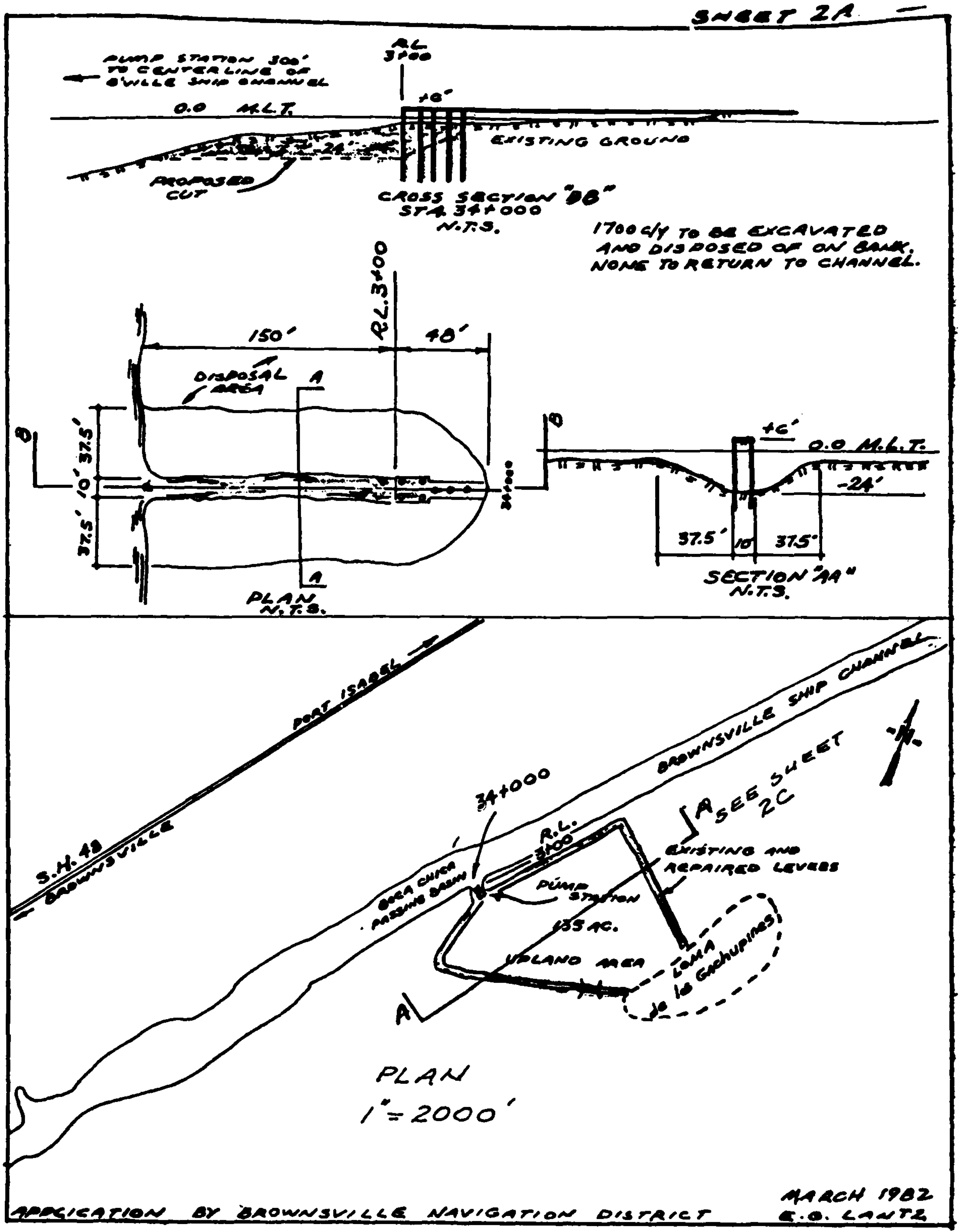
TRANSFEREE — DATE

☆ U.S. GOVERNMENT PRINTING OFFICE 1980-624-404 3-1

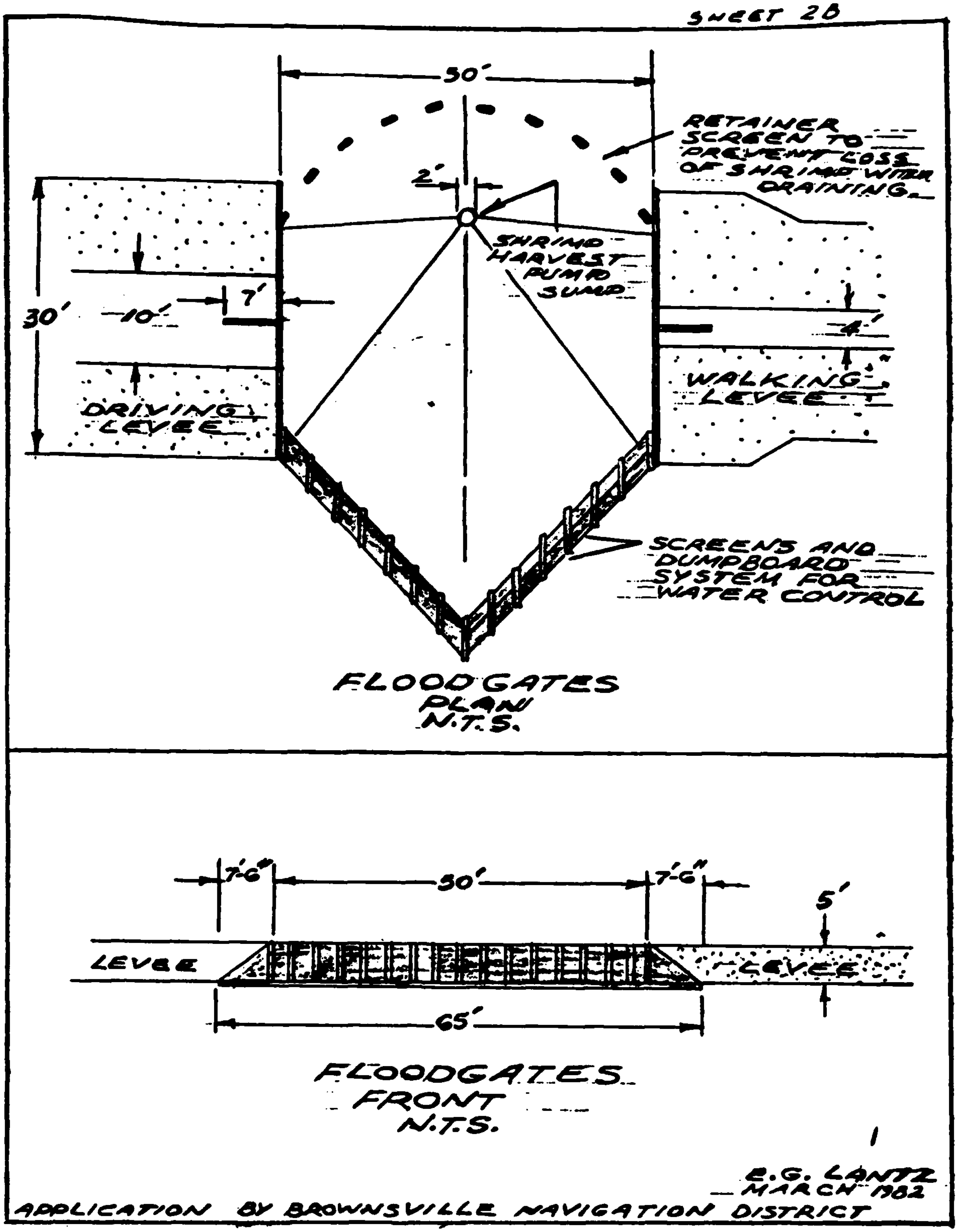

#FGD31
SHEET 1 OF 2
E.G. LANTZ
FEB 1982
N
0 5000 10000 15000 20000
PROPOSED PUMP INTAKE STRUCTURE AND CHANNEL
FISHING HARBOR CHANNEL
FM 1792
HWY. 4
RIO GRANDE RIVER
TURNING BASIN
OLD PORT ISABEL RD.
M.A.R.R.
HWY 48
BROWNSVILLE
FM 511
MERCEDES LINE RD.
S.P.R.R.
HWY 77/83
MATAMOROS

#16031

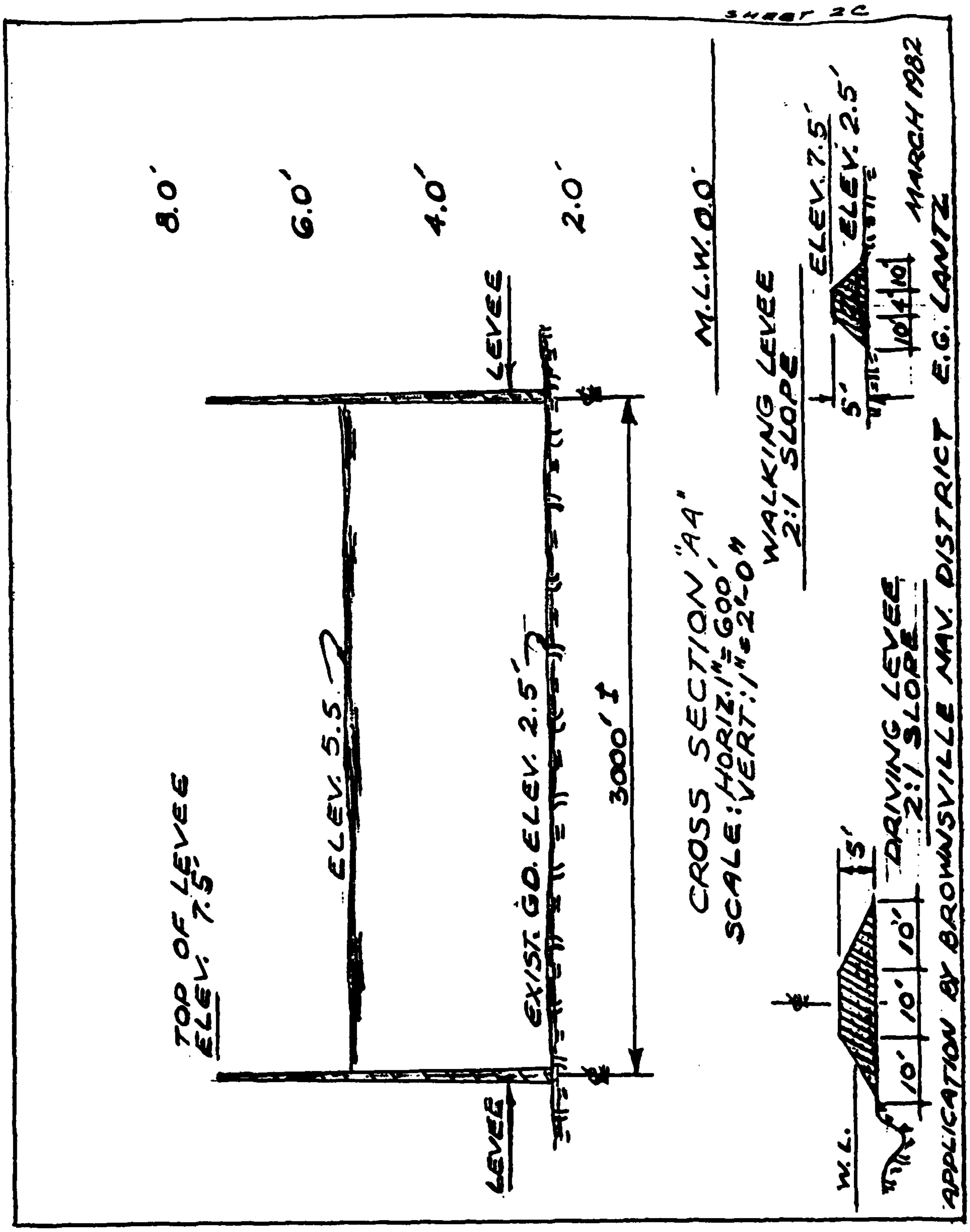
SHEET 2A



#16031


SHEET 2B
50'
RETAINER SCREEN TO PREVENT LOSS OF SHRIMP WITH DRAINING
2'
SHRIMP HARVEST PUMP SUMP
30'
10'
7'
4'
WALKING LEVEE
DRIVING LEVEE
SCREENS AND DUMPBOARD SYSTEM FOR WATER CONTROL
FLOODGATES
PLAN
N.T.S.
7'-6"
50'
7'-6"
5'
LEVEE
LEVEE
65'
FLOODGATES
FRONT
N.T.S.
1
E.G. LANTZ
MARCH 1982
APPLICATION BY BROWNSVILLE NAVIGATION DISTRICT

#16031


SHEET 2C
TOP OF LEVEE ELEV. 7.5'
ELEV. 5.5'
EXIST. GD. ELEV. 2.5'
3000'±
LEVEE
LEVEE
8.0'
6.0'
4.0'
2.0'
M.L.W. 0.0'
CROSS SECTION "AA"
SCALE: HORIZ. 1"= 600'
VERT. 1"= 2'-0"
WALKING LEVEE
2:1 SLOPE
ELEV. 7.5'
ELEV. 2.5'
5'
DRIVING LEVEE
2:1 SLOPE
W.L.
10'
10'
10'
5'
APPLICATION BY BROWNSVILLE NAV. DISTRICT
E.G. LANTZ
MARCH 1982

SHRIMP MARICULTURE: POSITIVE ASPECTS AND STATE OF THE ART

by
Addison L. Lawrence, Michael A. Johns
Texas Agricultural Experiment Station
and Department of Wildlife and
Fisheries Sciences
P. O. Drawer Q
Port Arkansas, Texas 78373

Wade L. Griffin
Department of Agricultural Economics
Texas A&M University
College Station, Texas 77843

Addison L. Lawrence

ABSTRACT

The emergence of shrimp mariculture as a new agricultural crop in the United States will occur during the next five years. Shrimp culture will not only provide food for human consumption and bait for the recreational fishery, but also there is the possibility of providing seedstock to supplement natural shrimp populations. The price of shrimp is high with shrimp representing the most valuable of the United States' fisheries. Of significance is the fact that the value of shrimp imported into the United States is almost double the value of the United States shrimp landings. Over 50% of the shrimp consumed in the United States are imported. Compounding the problem is the fact that the harvest from the oceans is either at or near maximum sustainable level. These facts plus the potential profit of greater than $200 per acre have made the interest in shrimp commercial culture extremely high. However, one of the strongest arguments for shrimp culture in the United States is the large potential revenue of over $2,000 per acre and the resulting large economic impact of greater than $6,000 per acre. In addition, there are millions of acres of land along the Gulf of Mexico and south Atlantic coast and inland in such areas as west Texas that can be used to raise shrimp on a commercial basis. These same lands are marginal for the traditional agricultural crops.

At this time, investment in shrimp mariculture has higher risk associated with it than other, more established industries. Several reasons for this

increased risk are: limited technology, the conversion from a research and development phase to a commercial phase, and the absence of established commercial ventures. Adding to the risk is the large initial capital outlay for construction of ponds to establish a commercial size operation.

INTRODUCTION

Shrimp mariculture is the production of marine shrimp under controlled environments in quantities for profit. It consists of three main phases: maturation/reproduction, hatchery, and grow-out (Figure 1). The maturation/reproduction phase represents that part concerned with the production of "seedstock" (shrimp larvae). This is accomplished by inducing female and male shrimp to mature, mate, and spawn in captivity producing live larvae. Also, shrimp larvae can be obtained from "sourcing," the capture of unmated and mated mature females from the ocean, and subsequent spawning of the female shrimp in captivity. "Seedstock" produced in the maturation/reproduction phase are used to supply the hatchery phase (larviculture). In the hatchery phase larvae are reared to 1-day-old postlarvae in approximately 10 to 12 days and, consequently, to a 5-day-old postlarvae in 15 days. Five- to 10-day-old postlarvae, which are 15- to 22-day-old shrimp, are used to supply the grow-out phase. The postlarvae are stocked into ponds, tanks, or raceways and reared to a size for food (3 to 6 months producing 15 to 40 count shrimp, heads-on) or bait (1-1/2 to 2-1/2 months producing 60 to 100 count shrimp, heads-on). In nature, the marine shrimp reproduce and complete their larval development (nauplii, protozoea, and mysis stages) in the open ocean (Figure 2). Upon metamorphosing to a miniature adult form called postlarvae (total body length, 7 to 15 mm), migration into the bays and estuaries occurs. In the bays and estuaries, the postlarvae shrimp reach juvenile size (usually 60 to 100 count shrimp, heads-on) and after 2 to 3.5 months migrate back into the ocean. The juvenile shrimp become sexually mature when they are 5 to 8 months old, depending upon species. The shrimp have a size of about 10 to 12 count, heads-on, when they initially become capable of reproducing. The females are slightly larger than the males at this time. This general description of the life history of marine shrimp is representative of the native white shrimp, *Penaeus setiferus* (Lindner and Anderson 1956; Lindner and Cook 1970; Renfro and Brusher 1982); pink shrimp, *Penaeus duorarum* (Costello and Allen 1970; Renfro and Brusher 1982); and brown shrimp, *Penaeus aztecus* (Cook and Lindner 1970; Renfro and Brusher 1982). There is one major difference between shrimp reared in captivity as compared to shrimp grown in nature. In nature, the percent of the larvae surviving to 20-25 g (18-22 count heads-on) size is much less than 1% whereas under culture conditions for commercial purposes the survival must be at least 20%.

The purpose of this paper is to describe briefly the role, state of the art, economic considerations, and positive aspects of shrimp mariculture in the United States.

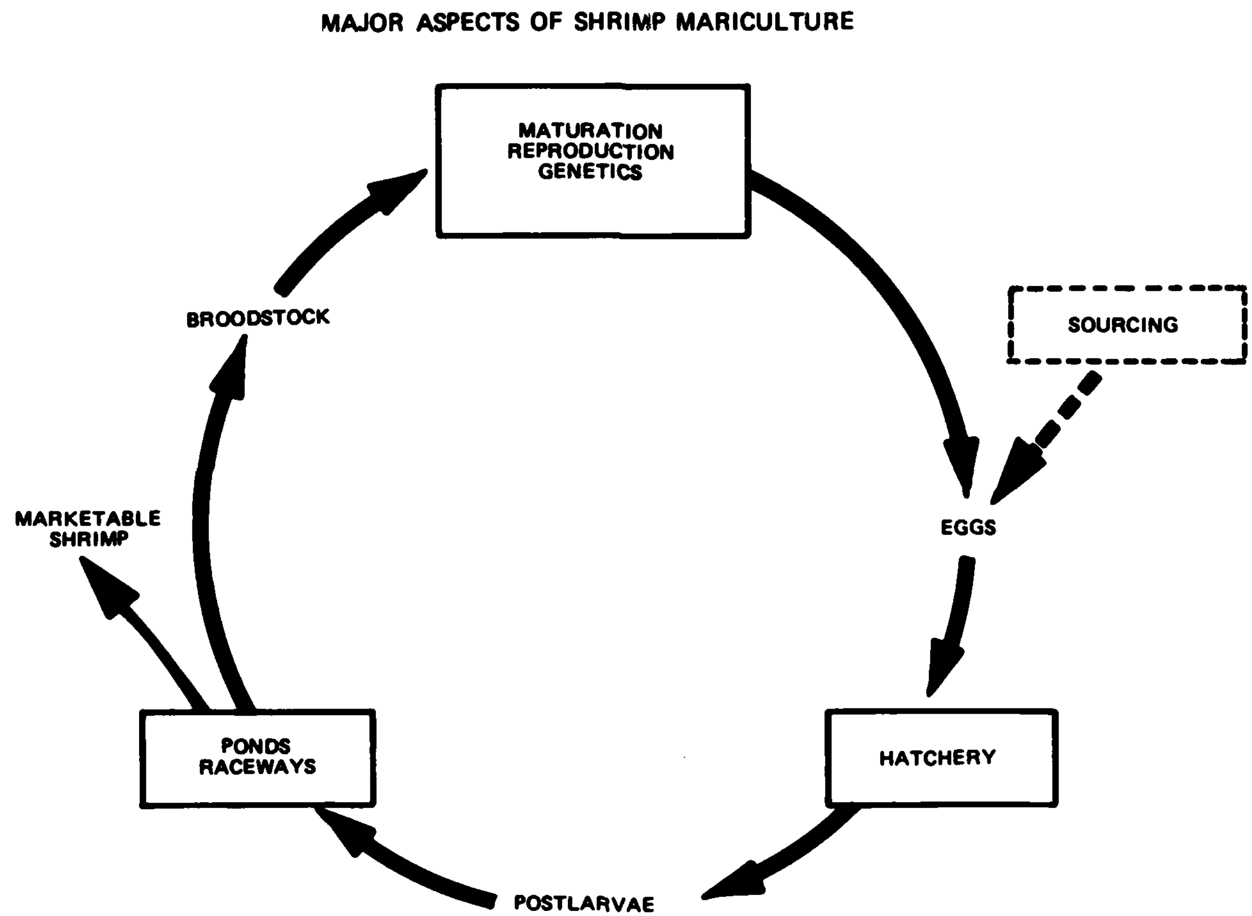


Figure 1. Major aspects of shrimp mariculture

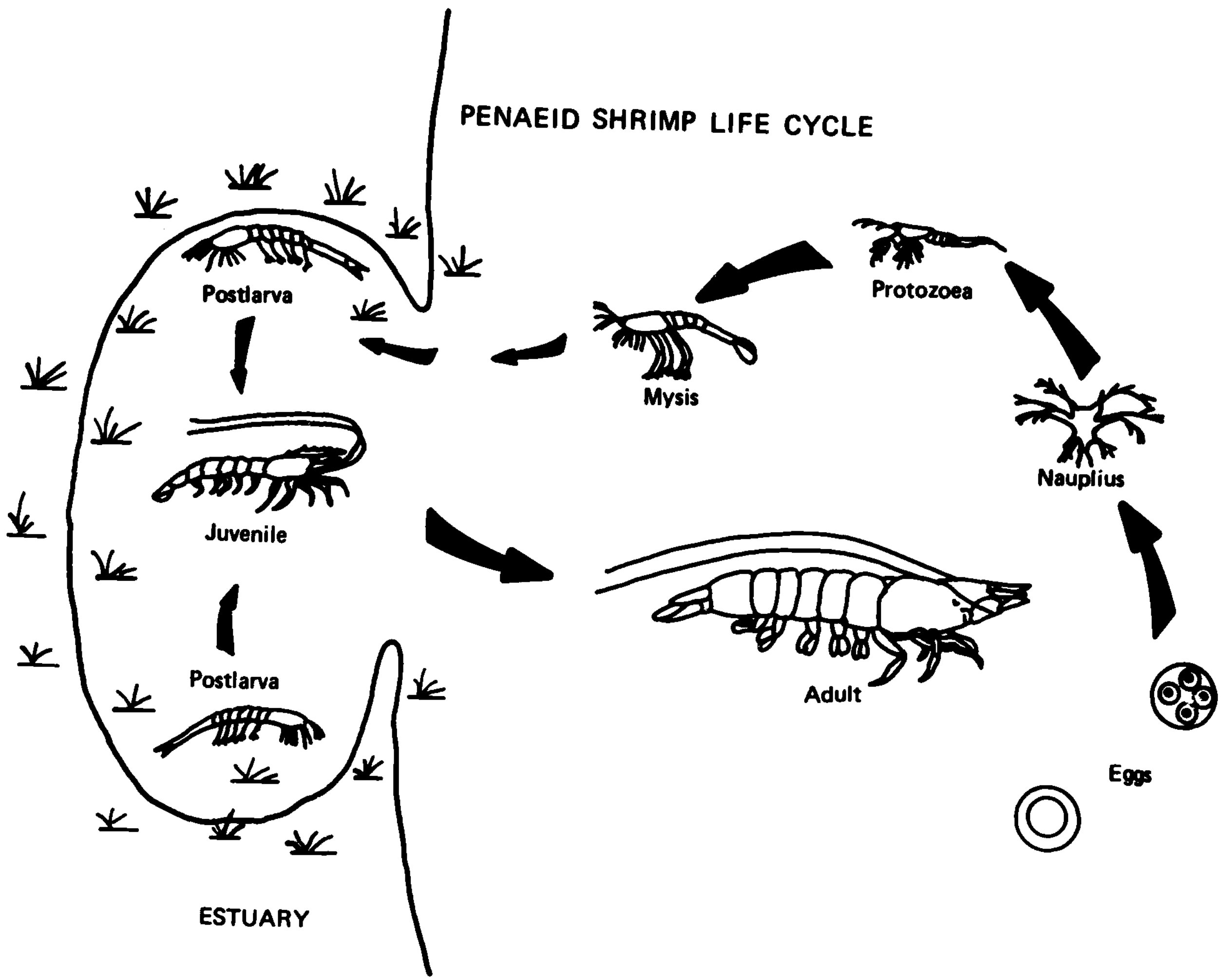


Figure 2. Generalized life cycle of marine shrimp

ROLE OF SHRIMP MARICULTURE

The three potential roles of shrimp mariculture are to provide:

a. Srimp for food for human consumption.

b. Shrimp for bait for the recreational fishing industry.

c. Seedstock for the supplementation of natural shrimp populations.

The importance and productivity of shrimp mariculture for rearing shrimp for human consumption and its contribution to the economy of a developing nation has been clearly demonstrated in Ecuador. With the technology approaching or at the threshold necessary for commercial shrimp farming in the United States, the development of shrimp mariculture on a commercial basis will probably occur in the United States within the next 3 to 5 years. Once shrimp mariculture becomes commercial, a significant economic impact in the United States could potentially occur quite rapidly. For example, in approximately ten years, the value of shrimp produced on farms in Ecuador has increased from essentially zero to about 80 million dollars per year. Comparing Ecuador, a developing nation, to the United States, where the amount of land and capital required for such ventures is more available, the development of shrimp farming will occur much more rapidly in the United States than in Ecuador. Furthermore, the presence of an existing shrimp processing and distributing system in the United States ensures this rapid commercialization.

Shrimp are used extensively for bait along the gulf and southeastern Atlantic coast. For example, there is a 30 to 40 million dollar per year shrimp bait industry in Texas. The rearing of shrimp on farms for bait may be more profitable than for food for human consumption. Shrimp used for bait are 60 to 100 count (heads-on) and have an exvessel value of about $4.00/pound. In contrast, the size of shrimp for human consumption having a value of approximately $4.00/pound at the producer level is 15 to 25 count (heads-on). Sixty to 100 count shrimp can be raised in two to three months whereas it takes five to six months to raise 15 to 25 count shrimp (Pardy et al. 1983). Thus, the cost for raising bait shrimp is approximately half that of raising table shrimp to those sizes which have the same selling price.

The stocking of bays and estuaries with juvenile shrimp raised in captivity is potentially possible since two species of native shrimp can now be matured in captivity in the United States (Lawrence et al. 1980; Brown and Lawrence 1983). Depending upon natural productivity and fishing pressure, the supplementation of the natural shrimp populations with shrimp raised in captivity is a definite possibility. This has already been done with success in the Seto Inland Sea of Japan (Maguire 1979; Kurata 1981). A similar releasing program for juvenile marine shrimp raised in captivity has been initiated off the coast of Kuwait (Al-Attar and Ikenoue 1979).

SHRIMP MARICULTURE: STATE OF THE ART

Presently, the major obstacle preventing commercial shrimp mariculture

in the United States and worldwide is the lack of a predictable source of "seedstock" (shrimp larvae) for the hatchery phase and, consequently, the limited availability of postlarvae for the grow-out phase.

The first report of maturation and reproduction of marine shrimp in the United States with the rearing of larvae to marketable size in captivity was reported by Lawrence et al. (1980) using the native species, *Penaeus setiferus*. Subsequently, two non-native species, *P. vannamei* and *P. stylirostris*, have been matured and spawned in captivity with viable offspring (Brown et al. 1980; Chamberlain and Lawrence 1981a, b). Recently, another native shrimp, *P. aztecus*, has been matured and spawned in captivity and the larvae reared to an average size of 2 g (Brown and Lawrence 1983).

The generalized requirements for maturation and reproduction of marine shrimp in captivity are given in Table 1. The ranges indicate the levels for the listed parameters that have been used. Three parameters, photoperiod, light intensity, and temperature, have been varied to obtain maturation and reproduction in captivity. In addition, unilateral eyestalk ablation has been shown to enhance maturation and spawning with viable nauplii for *P. vannamei, P. stylirostris, P. merguiensis, P. monodon,* and *P. japonicus* (Aquacop 1975, 1977; Beard et al. 1977; Primavera et al. 1978; Brown et al. 1980; Lawrence et al. 1980; Chamberlain and Lawrence 1981a, b).

Table 1

General Requirements for Maturation and Reproduction of Marine Shrimp in Captivity

Parameter	
*Light intensity	20 to 60 percent, variable
*Photoperiod	10 to 14 hours: 14:10 hours dark, variable
Water quality	Oceanic
Water exchange	5 to 150 percent depending upon presence of biofilters in tank
*Temperature	22°C to 28°C, variable
Salinity	26 to 34 ppt
Feeding rate	3 to 5 percent dry weight of biomass per tank per day, depending upon size of animal and species
Source of food	Fresh or fresh-frozen, preferably from more than one source, e.g. squid, shrimp, marine worm, clam, marine fish

* Variance of these parameters is known to be important for maturation/reproduction in captivity.

Another important development has been the successful intraspecific crosses using artificial insemination with *P. vannamei*, *P. stylirostris*, and *P. setiferus* (Persyn 1977; Bray et al. 1982, 1983; Sandifer et al. 1983). Also, using artificial insemination, sourcing cruises could represent an economically feasible means of supplementing the production of nauplii from maturation and reproduction in captivity to supply seedstock to commercial endeavors (Bray et al. 1982, 1983). Also, the successful intraspecific crosses using artificial insemination provide the basis for the initiation of genetic selection studies. Finally, artificial insemination will help solve the problems of lack of mating and spermatophore loss in captivity and provide the basis for studies concerned with the quality of sperm and ova. Another example of the tremendous advances that have been made in the area of maturation and reproduction was the successful mating of two different species, the native Gulf of Mexico white shrimp, *Penaeus setiferus*, with the Pacific Ocean blue shrimp, *Penaeus stylirostris*, by artificial insemination producing the first known marine shrimp hybrid (Lawrence et al. 1983a).

Table 2 summarizes the level of success of spawning for four species of marine shrimp that have been grown in ponds in the United States. The production of larvae from *P. stylirostris* in captivity is considered to be adequate to support commercial operation. The production of larvae from the remaining three species in captivity is inadequate to support a commercial operation (Johns et al. 1981). The recent improvement of the technology used to breed shrimp in captivity, the increased knowledge of the reproductive biology, and the advent of artificial insemination make the maturation and reproduction phase much less limiting and, thus, makes shrimp farming much more feasible.

Table 2

State of the Art for the Maturation and Reproduction Phase

Species	% Spawning Per Day	Larvae Per Spawn
Penaeus vannamei	0.5-4.0	50,000-100,000
Penaeus stylirostris	3.0-6.0	60,000-140,000
Penaeus setiferus	0.1-1.0	20,000- 80,000
Penaeus aztecus	0.1-1.0	5,000- 20,000

The hatchery or larval culture phase is considered adequate to support a commercial operation for the four species being considered for shrimp mariculture in the United States (*P. vannamei, P. stylirostris, P. setiferus, P. aztecus*). This level is generally accepted to be about 50 percent survival from the newly hatched larvae, the nauplius, to 5- to 10-day old postlarvae in 15 to 22 days. However, it is recognized that the hatchery

phase is not optimum and several areas need improvement. For example, some recent reports indicated a variability of the percent survival from the nauplial stage to 5-day-old postlarvae (Liao and Huang 1972; Shigueno 1975; Platon 1978; Beard and Wickins 1980; Mock et al. 1980a, b). The variability in percent survival may be due to differences in quality of batches of larvae (Brown 1972; Wickins 1972; Mock and Neal 1974, Beard et al. 1977; Cognie and Hirata 1978; Aquacop 1980), inconsistent quality of seawater used (Cook and Murphy 1966; Mock 1971), and variable and non-optimum feeding regimes (Wilkenfeld et al. 1981, 1983; Kuban et al. 1983).

There is no single standard method for rearing penaeid larvae to postlarvae though most people use 28 ppt, 28°C, and water as close to oceanic quality as possible. The rate of development and general dietary requirements for rearing larvae (Table 3) were basically described by the pioneering work of Hudinaga (1942). Following are a number of different genera of diatoms and phytoflagellates which have been used for rearing marine larvae with success: *Chaetoceros* (Platon 1978; Simon 1978; Jones et al. 1979), *Isochrysis* (Millamena and Aujero 1978; Wilkenfeld et al. 1981), *Nitzschia* (Hudinaga and Miyamura 1962; Laio and Huang 1972; Wickins 1976), *Phaedactylum* (Tabb et al. 1972; Wickins 1976); *Skeletonema* (Cook and Murphy 1969; Brown 1972; Mock and Neal 1974), *Tetraselmis* (Beard et al. 1977, Wickins and Beard 1978; Mock et al. 1980a), and *Thalassiosira* (Cook 1969; Wickins 1976; Emmerson 1980). Needless to say, there is insufficient information which would make it possible to identify single algal species, combinations of species, or feeding densities which would give the best production results in the larviculture of marine shrimp. Further, this does not even take into account different dietary requirements for the various larval stages for the different marine species (Kuban et al. 1983). Yet, in spite of this variability of methods and knowing that they are not optimum, commercial hatcheries exist in Panama, Taiwan, and Japan which are supporting successfully commercial grow-out ventures. It is generally accepted that the technology existing for this phase is adequate to support a commercial operation.

Table 3

Development Time and Food Preference

for Larviculture (Hatchery Phase)

Stage	Time (days)	Food Primary	Food Secondary
Nauplii	2.0-3.0	None	None
Protozoea	3.5-5.0	Plant	Animal
Mysis	3.5-5.0	Animal	Plant
Postlarvae	5.0-7.0	Animal	None

Pond culture of marine shrimp in the United States was pioneered by Lunz using *Penaeus aztecus*, *P. duorarum*, and *P. setiferus* (Lunz 1951, 1956, 1958, 1967; Lunz and Bearden 1963). He demonstrated that ponds could be used for producing shrimp for bait and food. Generally, the best production using single phase pond systems is greater than 500 lbs/acre (Broom 1968;

(Latapie et al. 1972; Neal and Latapie 1972; Gould et al. 1973; Parker and Holcomb 1973; Caillouet et al. 1974; Elam and Green 1974; Hysmith and Colura 1976; Rubright et al. 1981, Lawrence et al. 1983b), though as high as 1,941 lbs/acre has been obtained (Chamberlain et al. 1981). Also, two-phase pond systems, consisting of nursery and grow-out ponds, and three-phase pond systems, consisting of a nursery, intermediate, and grow-out ponds, have been used with best productions being 534 to 805 lbs/acre by Tatum and Trimble (1978) and Trimble (1980); and 1,833 lbs/acre by Parker et al. (1974), respectively. Further, two crops per season yielding a total of 845 lbs/acre and 2,094 lbs/acre has been reported by Tatum and Trimble (1978) and Lawrence et al. (1983b), respectively. All of the preceding production values are from ponds fed and fertilized. Latapie et al. (1972) and Rubright et al. (1981) obtained 42 to 267 lbs/acre and 218 lbs/acre, respectively, in ponds not fertilized and fed. Broom (1970) stated that shrimp production in ponds not fertilized and fed rarely exceeds 200 lbs/acre with yields being much higher in ponds receiving feed. Wheeler (1967, 1968) and Rubright et al. (1981) obtained increased shrimp production due to increased natural productivity with the addition of fertilizer to ponds. Quick and Morris (1976) postulated that the increased growth of brown shrimp (*P. aztecus*) in ponds containing dredged material was due to greater natural productivity as compared to ponds without dredged material. In fact, Quick et al. (1978) concluded that dredged material containment areas are both biologically and economically feasible for the culture of penaeid shrimp. More recently, blue shrimp, *P. stylirostris*, have been grown in ponds with natural productivity enhanced by the mixing of secondarily treated sewage with seawater (Landau et al. 1982).

In general, water of estuarine quality can be used for the pond production phase and temperature and salinity ranges of approximately 22 to 31°C and 10 to 50 ppt, respectively, are adequate for commercial production of *P. setiferus*, *P. vannamei*, and *P. stylirostris* in ponds for food. The predictability of pond production for the two best species, *P. vannamei* and *P. stylirostris*, has improved during the last two years. An example of the level of pond production which was obtained on an experimental basis is given in Table 4. The production of more than 2,000 pounds of heads-on shrimp/acre having an exvessel value of nearly $5,000 per acre was obtained for this experiment completed in October 1982. Also of significance has been the development of a commercial formulated shrimp feed for production in ponds in Texas and the production of the native white shrimp, *P. setiferus*, at a commercial level in ponds (Johns and Lawrence, unpublished data). This latter accomplishment along with artificial insemination and increased knowledge of the reproductive biology of *P. setiferus* has made this native species, along with *P. vannamei* and *P. stylirostris*, the three best shrimp species to be considered for pond production on a commercial basis in the United States. However, though it is recognized that technology for the grow-out phase in ponds is adequate for a commercial company to make a profit (Parker and Hayenga 1979; Adams et al. 1980), pond production can be further improved by using more optimum stocking densities (Pardy et al. 1983), fertilization and feeding regimes, formulated feeds, and water exchange rates.

Table 4

Stocking Density Experiment using *Penaeus vannamei*

Stocking Density	Production (Harvest) Data			
	Percent Survival	Size (grams)	Pounds Per Acre	Value ($) Per Acre
15,000	73*	20.50*	494*	1,477*
30,000	42	19.74	548	1,639
45,000	88	14.65	1,270	3,010
67,000	89	14.91	2,036	4,825
102,000	73*	10.50*	1,722*	3,565*

* Estimated values. Animals were stocked on June 30, 1982, at an average size of 2.93 g. Animals were harvested on October 4, 5, and 6. Producer level values as of October 1, 1982 (heads-on), were: 10.0 to 13.5 grams/animal, 2.07/lb; 13.6 to 15.8 grams/animal, 2.37/lb; 15.9 to 18.9 grams/animal, 2.60/lb; and 19.0 to 22.0 grams/animal, 2.99/lb.

ECONOMIC CONSIDERATIONS

The lack of production data from viable commercial shrimp culture facilities in the United States makes accurate economic analysis difficult. Though costs and returns data for various pond designs, facility sizes, production potentials, etc., can be generated, they cannot presently be substantiated due to the absence of successful commercial production units. Thus, the following economic considerations are useful only as a guide or planning tool and it should be kept in mind that the results are contingent on the assumptions set forth in their development. Prices for fixed and variable inputs are representative of the south Texas coastal area and reflect normal operating procedures for aquaculture ventures of this magnitude. Production potentials for *P. stylirostris* in ponds were derived from Pardy et al. (1983) who developed growth curves based on empirical data (from Texas) and the von Bertalanffy equation for growth. Data on costs were taken from Johns et al. (1983) which developed cost and return budgets for a 120-acre shrimp farm in south Texas.

Tables 5 and 6 present three different cases: a best case, an expected (average) case, and a least case. In Table 5, production is chosen based on downward adjustments in the growth curves presented in Pardy et al. (1983). Number of days of grow-out is determined by the maximum net revenue generated on a daily basis. The number of days in the pond along with stocking density and survival (among other factors) determine the size of shrimp at harvest. This, in turn, affects the price/lb received.

Table 6 presents the economic analysis for year 1 in a 10-year planning horizon for a 250-acre shrimp production unit. As in Table 5, three cases

Table 5

Assumptions for Table 6*

	Best Case	Expected Case	Least Case
Number of acres	250	250	250
Production (heads-off) Pounds/acre	1055	931	780
Days in pond	210	196	182
Size of shrimp (lb) at harvest	0.071	0.062	0.051
Price/lb (heads-off)	$ 5.43	$ 4.80	$ 4.80
Initial density/acre	40,000	40,000	40,000
Harvest density/acre	22,302	22,384	22,716
Percent survival	55.7	55.9	56.8

* The information contained in this table is based on Johns et al. (1983).

Table 6

Variable and Fixed Costs for Several Production Potentials for *P. Stylirostris**

	Best Case	Expected Case	Least Case
Gross revenue	$ 1,435,023	$1,119,848	937,346
Variable costs			
Seedstock	149,685	149,685	149,685
Feed	269,812	234,301	205,287
Labor	57,60	56,456	55,652
Other	73,285	73,157	73,033
TOTAL	$ 550,042	$ 513,599	$ 587,657
Fixed costs			
Salaries	43,200	43,200	43,200
Depreciation	86,254	86,254	86,254
Interest	267,480	267,302	266,626
Other	20,268	20,268	20,267
TOTAL FIXED COSTS	$ 417,201	$ 417,023	$ 416,347
TOTAL COST	$ 967,243	$ 930,622	$ 900,347
Net return (before tax)	$ 467,780	$ 189,226	$ 37,842
Federal income tax	215,180	87,044	7,568
Net return (after tax)	252,600	102,182	30,274
Required return to other equity	$ 88,101	88,101	88,101
Economic profit	$ 164,499	14,081	-57,827
Break-even price/lb	$ 3.66	3.99	4.60
Break-even production (lb)	36,504	35,121	33,965
Net profit/acre	$ 1,495.34	$ 408.72	121.10

* The information contained in this table is based on Johns et al. (1983).

are presented. Gross revenue is the product of price and production/250 acres for each case.

Variable costs are broken into four categories: seedstock, feed, labor, and other. Seedstock costs are based on an average price of $15/1000 post-larve. Feed is calculated at a price of $0.53/kg and the feed curve used is based on that presented in Chamberlain et al. (1981). Labor includes both full ($5.35/hour) and part-time ($3.35/hour) laborers used for daily feeding and maintenance, harvest, and processing. The "other" category includes personnel taxes, repair and maintenance, various supplies, etc.

Fixed costs are borken down into four categories: salaries, depreciation, interest, and other. The salary for a full-time manager was assumed to be $3,600. Depreciation is calculated using the straightline method. Interest is high in the first few years but becomes less of a cost item after 5 years.

Net return is the difference between gross revenue and total cost. Federal income tax is based on a corporate tax schedule for the year of 1982. Required return to owner equity is the amount required by the entreprenuer for his portion of the investment. Economic profit takes into account the return to owner equity (a cost) and is derived by subtracting the required return from the net return (after tax).

Break-even price is the price necessary (at the given level of production) to cover total costs. In other words, break-even price represents the lowest price that can be received by entreprenuer that will allow him to cover all costs. Break-even production is the production required at the given price/lb to just equal total cost.

Basically the results in Table 6 show the economic potential of shrimp culture along with the economic impact of growth on profit. A number of factors affect the profitability of shrimp culture operations. Several of these factors having a major impact on the production side are grow-out period, survival, growth rate, and stocking density. On the cost side there are land and construction costs in the initial investment, seedstock and feed in production, and interest and depreciation in fixed costs. In order to gain a perspective on the effect changes in these parameters have on profit, sensitivity analyses need to be performed. Sensitivity analyses have been performed on several of these parameters (Hanson 1979; Adams et al. 1980; Griffin et al. 1981; Johns et al. 1983; Pardy et al. 1983). Information from these and other analyses aid in increasing production and reducing costs (i.e. maximizing profit).

POSITIVE ASPECTS OF SHRIMP MARICULTURE

The harvesting of many marine animals is predicted to soon reach a maximum natural sustainable production level (National Oceanic and Atmospheric Administration 1980; Robinson 1982). In fact, some marine species already have been harvested to such an extent that decreased commercial yields have resulted in economic losses for some countries of the world.

Similarly, it is assumed that the commercial harvest of marine shrimp is either at, or very close to, the maximum sustainable yield. For example, the commercial catch by United States fisherman has been constantly just

above 200 million pounds since 1972 (Table 7) as reported by National Marine Fisheries Service (1973, 1974, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1982). Another example is that the shrimp harvested by Ecuadorian fishermen has decreased by 20 percent during the last decade though the shrimping fleet size has remained the same (Anonymous 1982). The problem of an adequate supply has been compounded during the last decade by a 20 percent per capita increase in the world's demand for fishery products, and an additional increase is predicted for the future. In fact, the world and United States shellfish and fish markets were predicted to increase by 25 and 33 percent, respectively, between 1975 and 1985 (Bell et al. 1977).

Table 7

Shrimp Landing, Imports, and Value in the United States from 1972 through 1981

	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
U. S. commercial shrimp										
Landings (Mil.lbs)*	235	227	226	209	246	291	258	205	207	217
Value (Mil.$)	193	219	178	226	331	355	386	471	403	463
U. S. imported shrimp										
Million pounds	223	203	229	201	230	228	198	225	219	223
Value (Mil.$)	250	282	387	346	463	492	422	713	719	724

* Landings are heads-off. Also U. S. fisherman started being shared out of Mexican waters in 1977. Ten percent of the Gulf of Mexico catch was from Mexican waters.

Shrimp culture is evolving into a new industry for both developed and developing countries. It represents a source of income which can provide a basis for new economic growth and development. An excellent example of this is the significant increase in the import of shrimp into the United States by two developing countries, Ecuador and Panama. Table 8 shows the significant increase in shrimp imported into the United States by these two countries vs. countries in which shrimp mariculture development has not been significant (National Marine Fisheries Service 1978, 1979, 1980, 1981, 1982). Since 1977, there has been a 40 percent per year increase in production of pond-grown shrimp in Ecuador and, presently, 80 percent of all the shrimp exported from Ecuador are farmed raised (Anonymous 1982; Hirono 1983). In 1981, marine shrimp were the most valuable renewable resource in Ecuador surpassing bananas, coffee, and cacao and the second most valuable commodity exported by Ecuador--oil was the most valuable (Hirono 1983). The tremendous increase in marine shrimp imported into the United States from Ecuador (Table 8) has occurred during a period that there has been a 20 percent decrease in the commercial catch from natural sources (Anonymous 1982).

Though shrimp has been the most valuable of the United States fisheries for the last 5 years, approximately half of the shrimp consumed in the United States since 1973 has been imported (Table 7) (National Marine Fisheries Service 1973, 1974, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1982). In

Table 8

Amounts (in thousands of pounds) of Shrimp Imported Into the United States from 1977 to 1981 by Ecuador, India, Mexico, Nicaragua, and Panama

Country	Year 1977	1978	1979	1980	1981
Countries Having Significant Shrimp Mariculture in 1981					
Ecuador	8,613	10,446	13,703	20,195	24,735
Panama	10,862	10,261	12,199	13,727	15,923
Countries Not Having Significant Shrimp Mariculture in 1981					
India	41,111	39,160	30,785	12,999	18,998
Mexico	76,252	72,451	71,891	76,062	70,866
Nicaragua	7,387	5,575	5,397	5,624	3,499

1981, the value of shrimp imported into the United States was $724 million as compared to United States shrimp landings valued at $463 million. Thus, with no potential increase in shrimp harvested from natural sources and the large amount of shrimp imported, large quantities of shrimp could be potentially produced by shrimp culture in the United States without affecting the United States shrimping industry.

There is a large amount of land available along the Gulf of Mexico and southern Atlantic coasts of the United States which can be used for shrimp mariculture. For example, the 70 to 90 percent of the land adjacent to the Texas coastline (2,000 to 2,500 miles) has a soil composition adequate for shrimp mariculture (Stickney and Davis 1981). This 1/4- to 1/2-mile-wide strip of land is too salty for traditional agricultural crops such as cotton, grain sorghum, and cattle. This marginal land for traditional crops can be utilized for agricultural production through the development of shrimp mariculture. In addition, the temperature of the Texas coast is adequate for a 5- to 6-month growing season near the Beaumont-Port Arthur (Jefferson County) area to a 6.5- to 7.5-month near Brownsville-Port Isabel (Cameron County) area. The length of the growing season is more than adequate for a minimum of one crop to possibly two crops per year along the Gulf of Mexico and southern Atlantic coasts (Lawrence et al. 1983b). Also of significance is the fact that there are inland areas which have saltwater near the surface. An example of this is west Texas. Marine shrimp could potentially be raised in these areas. Further, some of these areas, such as in west Texas, are in need of a new agricultural crop due to the scarcity of fresh water for irrigation.

Several species of marine shrimp have been cultured in ponds at commercial levels. Table 9 summarizes the state of the art for the culture of three species of marine shrimp in ponds in Alabama (Tatum and Trimble 1978; Trimble 1980), Florida (Caillouet et al. 1974), Louisiana (Broom 1968; Latapie et al. 1972, Neal and Latapie 1972), and Texas (Gould et al. 1973; Parker and Holcomb 1973; Elam and Green 1974; Parker et al. 1974; Hysmith and Colura 1976; Chamberlain et al. 1981; Rubright et al. 1981; Lawrence et al. 1983b). Profits can be potentially obtained from the above production levels (Table 5). Of equal significance is the potential economic impact of shrimp mariculture on local, state, and national levels. Taking into consideration transportation, processing, marketing, etc., the total economic impact is approximately three times the producer level value (gross revenue in Table 5). Thus, using the expected case as an example, the economic impact of only 250 acres of water potentially could be approximately $3,360,000. In conclusion, the decreasing natural production of shrimp, the large shrimp market, the potential for decreasing the amount of shrimp imported, the large amount of available land along the Gulf of Mexico and southern Atlantic coasts, and, finally, the large potential economic impact of shrimp mariculture makes this emerging new industry very important to the United States. Shrimp mariculture is becoming more and more attractive to investors because of the increasing level of technology and the success of shrimp culture on a commercial basis in Ecuador.

Table 9

Culture of Marine Shrimp in Ponds: State of the Art

Species (*Penaeus*)	Production (lbs/acre)	Heads-on Count (no/lb)	Percent Survival
P. vannamei	600-2000	20-40	50-90
P. stylirostris	500-1200	20-40	30-70
P. setiferus	500-1200	25-40	30-40

SUMMARY

The three potential roles of shrimp mariculture are to provide:

a. Shrimp for food for human consumption.

b. Shrimp for bait for the recreational fishing industry.

c. Seedstock for the supplementation of natural shrimp populations.

The maturation and reproduction of penaeid shrimp is still the most limiting phase for the development of shrimp mariculture on a commercial basis. However, recent technological developments for this phase, the continued improvement in the technology associated with larviculture (hatchery) and pond grow-out phases, and the tremendous success of shrimp farming in Central America are making shrimp mariculture very attractive to commercial

interests in the United States. The facts that the shrimp market is very large, the harvest of shrimp from the oceans is either at or very near a maximum sustainable yield, and the potential high profit of greater than $200/acre/crop are adding to this attractiveness.

Shrimp mariculture or ranching has a great potential benefit and economic return to the United States because:

a. The gross revenue of probably $1,000 to $3,000/acre/crop results in a very large economic impact.

b. Land which is marginal for the traditional agricultural crops can be used.

c. At least 50% of the shrimp consumed in the U.S. is imported.

The emergence of shrimp mariculture as a new agricultural crop will occur during the next five years. With this in mind, the next five years is a very critical period in the continued development and refinement of culture technology with the subsequent demonstration of consistent production, which will lead to the establishment of a strong and viable shrimp culture industry in the United States. This developmental phase will be a period of extremely high risk for the potential investor.

ACKNOWLEDGEMENTS

The authors wish to express their gratitude to the Texas Agricultural Experiment Station, Texas Agricultural Extension Service, and Texas A&M University's Sea Grant College Program, supported by the National Oceanic and Atmospheric Administration Office of Sea Grant, Department of Commerce, under Grant No. 4-7-158-44105, for their continued support of the Shrimp Mariculture Program. Special recognition is due to the Caesar A. Kleberg Foundation for Wildlife Conservation for their support of the Shrimp Mariculture Project at Corpus Christi. The support of the Caesar A. Kleberg Foundation has greatly enhanced the development of the Shrimp Mariculture Project and has been largely responsible for the significant research accomplished the last two years.

We also are grateful to the U. S. Army Corps of Engineers for providing the support for this very timely workshop. Mr. John Lunz and Mr. Jurij Homziak of the U. S. Army Engineer Waterways Experiment Station are warmly thanked for their help, patience, and understanding. Thanks are also due to Ginny Mitchell for the many extra hours she spent in editing and typing this manuscript.

LITERATURE CITED

Adams, C. M., W. L. Griffin, J. P. Nichols and R. W. Brick. 1980. Bioengineering-economic model for shrimp mariculture system, 1979. Texas A&M University Sea Grant College Program Technical Report TAMU-SG-80-203. 125 pp.

Al-Attar, M. H. and H. Ikenoue. 1979. The production of juvenile shrimps (*Penaeus semisulcatus*) for release off the coast of Kuwait during 1975. Kuwait Bulletin of Marine Science 1:1-31.

Anonymous. 1982. Fishing exports now second largest. Pages 148 to 156 in W. R. Spurrier (ed.), Weekly Analysis of Ecuadorian Issues Number 18.

Aquacop. 1975. Maturation and spawning in captivity of penaeid shrimp: *Penaeus merguienses* de Man, *Penaeus japonicus* Bates, *Penaeus aztecus* Ives, *Metapenaeus ensis* de Haan *Penaeus semiculcatus* de Haan. Proceedings World Mariculture Society 6:123-132.

Aquacop. 1977. Reproduction in captivity and growth of *Penaeus monodon*, Fabricius in polynesia. Proceedings World Mariculture Society 8:927-945.

Aquacop. 1980. Penaeid reared broodstock: closing the cycle of *P. monodon*, *P. stylirostris* and *P. vannamei*. Centre Oceanologique du Pacifique, CNEXO-COP, Tahitai. 12 pp.

Beard, T. W. and J. F. Wickins. 1980. Breeding of *Penaeus monodon* Fabricius in laboratory recirculation systems. Aquaculture 20:79-89.

Beard, T. W., J. F. Wickins and D. R. Arnstein. 1977. The breeding and growth of *Penaeus merguienses* de Man in laboratory recirculation systems. Aquaculture 10:275-289.

Bell, F. W., D. A. Nash, E. W. Carlson, F. V. Waugh, R. K. Kinoshita and R. Fullenbaum. 1977. The future of the world's fishery resources, forecast of demand, supply, and prices to the year 2000 with a discussion of implications for public policy. National Marine Fisheries Service Economic Research Laboratory File Manuscript. 419 pp.

Bray, W. A., G. W. Chamberlain and A. L. Lawrence. 1982. Increased larval production of *Penaeus setiferus* by artificial insemination during sourcing cruises. Journal World Mariculture Society 13:(in press).

Bray, W. A., G. W. Chamberlain and A. L. Lawrence. 1983. Observations on natural and artificial insemination of *Penaeus setiferus*. Proceedings First International Conference on Warm Water Aquaculture--Crustacea 1: (accepted for presentation).

Broom, J. G. 1968. Pond culture of shrimp on Grand Terre Island, Louisiana, 1962-1968. Proceedings Gulf and Caribbean Fisheries Institute 21:137-151.

Broom, J. G. 1970. Shrimp culture. Proceedings World Mariculture Society 1:63-68.

Brown, A., Jr. 1972. Experimental techniques for preserving diatoms used as food for larval *Penaeus aztecus*. Proceedings National Shellfisheries Association 62:21-25.

Brown, A., Jr. and A. L. Lawrence. 1983. Maturation and reproduction of the brown shrimp, *Penaeus aztecus*, under controlled laboratory conditions. (in preparation).

Brown, A., Jr., J. P. McVey, B. M. Scott, T. D. Williams, B. S. Middleditch and A. L. Lawrence. 1980. The maturation and spawning of *Penaeus stylirostris* under controlled laboratory conditions. Proceedings World Mariculture Society 11:488-499.

Caillouet, C. W., J. P. Norris, E. J. Herald and D. C. Tabb. 1974. Growth and yield of pink shrimp (*Penaeus duroarum* Burkenroad) in a feeding experiment in ponds. Proceedings World Mariculture Society 5:125-135.

Chamberlain, G. W. and A. L. Lawrence. 1981a. Maturation, reproduction and growth of *Penaeus vannamei* and *P. stylirostris* fed natural diets. Journal World Mariculture Society 12:209-224.

Chamberlain, G. W. and A. L. Lawrence. 1981b. Effect of light intensity and male eyestalk ablation on reproduction of *Penaeus stylirostris* and *Penaeus vannamei*. Journal World Mariculture Society 12: (in press).

Chamberlain, G. W., D. L. Hutchins and A. L. Lawrence. 1981. Mono- and polyculture of *Penaeus vannamei* and *Penaeus stylirostris*. Journal World Mariculture Society 12:251-270.

Cognie, D. and T. Hirata. 1978. Elevage larvaire de penaeids a l'echelle pilote. Raporte de la Centre National pour L'exploitation Des Oceans, Base Oceanologique de Mediterranee. 14 pp.

Cook, H. L. 1969. A method of rearing penaeid shrimp for experimental studies. Food and Agricultural Organization of the United Nations Fisheries Report 57, Vol 3:709-715.

Cook, H. L. and M. A. Murphy. 1966. Rearing penaeid shrimp from eggs to postlarvae. Proceedings of the Conference of the Southeast Association of Game Commissioners 19:283-288.

Cook, H. L. and M. A. Murphy. 1969. The culture of larval penaeid shrimp. Transactions of the American Fisheries Society 98:751-754.

Cook, H. L. and M. J. Lindner. 1970. Synopsis of biological data on the brown shrimp *Penaeus aztecus aztecus* Ives, 1891. Food and Agricultural Organization of the United Nations Fisheries Report 57, Vol 4:1471-1497.

Costello, T. J. and D. M. Allen. 1970. Synopsis of biological data on the pink shrimp *Penaeus duorarum duorarum* Burkenroad, 1939. Food and Agricultural Organization of the United Nations Fisheries Report 57, Vol 4:1499-1537.

Elam, L. L. and A. W. Green. 1974. Culture of white shrimp (*Penaeus setiferus*, Linnaeus) in static water ponds. Proceedings World Mariculture Society 5:87-96.

Emmerson, W. D. 1980. Ingestion, growth and development of *Penaeus indicus* larvae as a function of *Thalassiosira weisflogii* cell concentration.

Gould, R. A., D. V. Aldrich and C. R. Mock. 1973. Experimental pond culture of brown shrimp (*Penaeus aztecus*) in power plant effluent water. Proceedings World Mariculture Society 4:195-213.

Griffin, W. L., J. S. Hanson, R. W. Brick and M. A. Johns. 1981. Bioeconomic modeling with stochastic elements in shrimp culture. Journal World Mariculture Society 12:94-103.

Hanson, J. S. 1979. An economic model incorporating shrimp growth and water quality parameters into a budget simulation. Master's Thesis. Texas A&M University. 175 pp.

Hirono, Y. 1983. Preliminary report on shrimp culture activities in Ecuador. Journal World Mariculture Society (accepted for publication).

Hudinaga, M. 1942. Reproduction, development and rearing of *Penaeus japonicus* Bate. Japanese Journal of Zoology 10:305-393.

Hudinaga, M. and M. Miyamura. 1962. Breeding of the kurama prawn (*Penaeus japonicus* Bate). Journal Oceanographic Society of Japan, 20th Anniversary 20:696-706.

Hysmith, B. T. and R. L. Colura. 1976. Effect of salinity on growth and survival of penaeid shrimp in ponds. Proceedings World Mariculture Society 7:289-303.

Johns, M., W. Griffin, A. Lawrence and D. Hutchins. 1981. Budget analysis of shrimp maturation facility. Journal World Mariculture Society 12:104-112.

Johns, M. A., W. L. Griffin, C. Pardy and A. L. Lawrence. 1983. Pond production strategies and budget analysis for penaeid shrimp. Proceedings First International Biennial Conference on Warm Water Aquaculture-Crustacea 1: (accepted for publication).

Johns, M. A., A. Kanazawa and S. Abdel Rahman. 1979. Studies on the presentation of artificial diets for rearing the larvae of *Penaues japonicus* Bate. Aquaculture 17:33-43.

Kuban, F. D., J. S. Wilkenfeld and A. L. Lawrence. 1983. Survival and growth of *Penaeus setiferus L.* and *Penaeus aztecus* Ives larvae fed *Artemia* beginning at the protozoea-two substage versus the mysis-one substage. Journal World Mariculture Society 13: (accepted for publication).

Kurata, H. 1981. Shrimp fry releasing techniques in Japan, with special reference to the artificial tideland. Kuwait Bulletin Marine Science 2:117-147.

Landau, M., R. H. Pierce, J. H. Ryther and J. A. Zeigler. 1982. The quality of shrimp reared in a sewage/seawater aquaculture system. American Zoologist 22:912.

Latapie, W. R., Jr., J. G. Brown and R. A. Neal. 1972. Growth rates of *Penaeus aztecus* and *P. setiferus* in artificial ponds under varying conditions. Proceedings World Mariculture Society 3:241-254.

Lawrence, A. L., J. P. McVey, M. A. Johns and W. L. Griffin. 1983b. Production of two shrimp crops per year in south Texas using a single phase pond production system. Proceedings First International Biennial Conference on Warm Water Aquaculture--Crustacea. 1: (accepted for publication).

Lawrence, A. L., L. T. Lester and W. A. Bray. 1983a. Successful interspecific cross between *Panaeus setiferus* and *P. stylirostris* using artificial insemination (in preparation).

Lawrence, A. L., Y. Akamine, B. S. Middleditch, G. W. Chamberlain and D. L. Hutchins. 1980. Maturation and reproduction of *Penaeus setiferus* in captivity. Proceedings World Mariculture Society 11:481-487.

Liao, I. C. and T. L. Huang. 1972. Experiments on the propagation and culture of prawns in Taiwan. Pages 328-354 in T.V.R. Pillay (ed.). Coastal Aquaculture in the Indo-Pacific Region. Fishing News (Books) Lts., Surrey. 497 pp.

Lindner, M. J. and H. L. Cook. 1970. Synopsis of biological data on the white shrimp *Penaeus setiferus* (Linnaeus) 1767. Food and Agriculture

Organization of the United Nations Fisheries Report 56, Vol 4:1439-1469.

Lindner, M. J. and W. W. Anderson. 1956. Growth, migrations, spawning and size distribution of shrimp *Penaeus setiferus*. United States Fish and Wildlife Service Fishery Bulletin 56:553-645.

Lunz, G. R. 1951. A salt water fish pond. Contributions, Bears Bluff Laboratories, South Carolina 12:1-12.

Lunz, G. R. 1956. Harvest from an experimental one-acre salt-water pond at Bears Bluff Laboratories, South Carolina. Progressive Fish Culturist 19:92-94.

Lunz, G. R. 1958. Pond cultivation of shrimp in South Carolina. Gulf and Caribbean Fisheries Institute, 10th Annual Session 10:44-48.

Lunz, G. R. 1967. Farming the salt marshes. Proceedings Marsh and Estuary Management Symposium, Louisiana State University Press 1:172-177.

Lunz, G. R. and C. M. Bearden. 1963. Control of predacious fishes in shrimp farming in South Carolina. Contributions Bears Bluff Laboratory, Number 36. 96 pp.

Maguire, G. B. 1979. A report on the prawn farming industries of Japan, the Philippines and Thailand. N.S.W. State Fisheries Technical Report, 110 pages.

Millamena, O. and E. J. Aujero. 1978. Preserved algae as food for *Penaeus mondon* larvae. SEAFDEC, Quarterly Research Report 2:15-16.

Mock, C. R. 1971. Larval culture of penaeid shrimp at the Galveston Biological Laboratory, Contribution No. 344 from the National Marine Fisheries Service, Galveston Laboratory, Galveston. pp 33-40.

Mock, C. R. and R. A. Neal. 1974. Penaeid shrimp hatchery systems. Proceedings of the FAO CARPAS Symposium on Aquaculture, Montevideo, Uraguay, 26 Nov. - 2 Dec. 9 pp.

Mock, C. R., C. T. Fontaine and D. B. Revera. 1980a. Improvements in rearing larval penaeid shrimp by the Galveston Laboratory method. Pages 331-342 in G. Persoone, P. Sorgeloos, O. Roels and E. Jaspers (eds.). The Brine Shrimp *Artemia* Volume 3. Ecology, Culture, Use in Aquaculture. Universa Press. Wetteren. 456 pp.

Mock, C. R., D. B. Revera and C. T. Fontaine. 1980b. Larval culture of *Penaeus stylirostris* using modifications of the Galveston Laboratory technique. Proceedings World Mariculture Society 11:102-117.

National Marine Fisheries Service. 1973. Fisheries of the United States, 1972. Current fishery statistics No. 6400. Washington Government Printing Office. 106 pp.

National Marine Fisheries Service. 1974. Fisheries of the United States, 1973. Current fishery statistics No. 6700. Washington Government Printing Office. 98 pp.

National Marine Fisheries Service. 1975. Fisheries of the United States, 1974. Current fishery statistics No. 6900. Washington Government Printing Office. 100 pp.

National Marine Fisheries Service. 1976. Fisheries of the United States, 1975. Current fishery statistics No. 7200. Washington Government Printing Office. 96 pp.

National Marine Fisheries Service. 1977. Fisheries of the United States, 1976. Current fishery statistics No. 7500. Washington Government Printing Office. 112 pp.

National Marine Fisheries Service. 1978. Fisheries of the United States, 1977. Current fishery statistics No. 7700. Washington Government Printing Office.

National Marine Fisheries Service. 1979. Fisheries of the United States, 1978. Current fishery statistics No. 7800. Washington Government Printing Office. 120 pp.

National Marine Fisheries Service. 1980. Fisheries of the United States, 1979. Current fishery statistics No. 7900. Washington Government Printing Office. 128 pp.

National Marine Fisheries Service. 1981. Fisheries of the United States, 1980. Current fishery statistics No. 8100. Washington Government Printing Office. 132 pp.

National Marine Fisheries Service. 1982. Fisheries of the United States, 1981. Current fishery statistics No. 8200. Washington Government Printing Office. 131 pp.

National Oceanic and Atmospheric Administration. 1980. National aquaculture plan (Draft). Washington Government Printing Office. 532 pp.

Neal, R. A. and W. R. Latapie, Jr. 1972. Pond culture on Grand Terre Island, Louisiana, 1969-1971. Proceedings World Mariculture Society 3:227-240.

Pardy, C. R., W. L. Griffin, M. A. Johns and A. L. Lawrence. 1983. A preliminary economic analysis of stocking strategies for penaeid shrimp culture. Journal World Mariculture Society. (Submitted for publication).

Parker, J. C. and H. W. Holcomb, Jr. 1973. Growth and production of brown and white shrimp (*Penaeus aztecus* and *P. setiferus*) from experimental ponds in Brazoria and Orange counties, Texas. Proceedings World Mariculture Society 4:215-234.

Parker, J. C. and W. A. Hayenga. 1979. An analysis of the investment considerations for penaeid shrimp mariculture in pond systems. (Unpublished manuscript).

Parker, J. C., F. S. Conte, W. S. MacGrath and B. W. Miller. 1974. An intensive culture system for penaeid shrimp. Proceedings World Mariculture Society 5:65-79.

Persyn, H. O. 1977. Artificial insemination of shrimp. United States patent no. 4,031,855. June 28, 1977. 4 pp.

Platon, R. R. 1978. Design, operation and economics of a small-scale hatchery for the larval rearing of sugpo, *Penaeus monodon* Fabricius. SEAFDEC Aquaculture Extension Manual No. 1. 30 pp.

Primavera, J. H., E. Borlongan and R. A. Posadas. 1978. Mass production in concrete tanks of sugpo *Penaeus monodon* Fabricius spawners by eyestalk ablation. Fisheries Research Journal of the Philippines 3:1-12.

Quick, J. A., Jr., and J. A. Morris. 1976. Experimental extensive culture of penaeid shrimp in a simulated dredged material disposal area. Proceedings World Mariculture Society 7:305-326.

Quick, J. A., Jr., D. J. Milligan, S. E. Hill, R. J. Hover and W. F. McIlhenny. 1978. Field demonstration of shrimp mariculture feasibility in dredged material containment areas. Dredged Material Research Program, U. S. Corps of Engineers Technical Report D-78-53. 128 pp.

Renfro, W. C. and H. A. Brusher. 1982. Seasonal abundance, size distribution, and spawning of three shrimps (*Penaeus aztecus, P. setiferus* and *P. duorarum*) in the northwestern Gulf of Mexico, 1961-62. NOAA Technical Memorandum NMFS-SEFC-94. 3 Tables, 10 Figures, 24 pp.

Robinson, M. A. 198_. Prospects for world fisheries to 2000. Food and Agriculture Organization of the United Nations Fisheries Circular No. 722, Revision 1:16 pp.

Rubright, J. S., J. L. Harrell, H. W. Holcomb and J. C. Parker. 1981. Responses of planktonic and benthic communities to fertilizer and feed applications in shrimp mariculture ponds. Journal World Mariculture Society 12:281-299.

Sandifer, P. A., A. V. Berg, A. L. Lawrence and G. W. Chamberlain. 1983. Improved methods for artificial insemination of penaeid shrimp. (In preparation).

Shigueno, K. 1975. Shrimp Culture in Japan. Association for International Technical Promotion, Tokyo, Japan. 153 pp.

Simon, C. M. 1978. The culture of the diatom *Chaetoceros gracilis* and its use as a food for penaeid protozoeal larvae. Aquaculture 14:105-113.

Stickney, R. R. and J. T. Davis. 1981. Aquaculture in Texas, a status report and development plan. Texas A&M University Sea Grant Program Publication, TAMU-SG-81-119. 103 pp.

Tabb, D. C., W. T. Yang, Y. Hirono and J. Heinen. 1972. A manual for culture of pink shrimp *Penaeus duorarum*, from eggs to postlarvae suitable for stocking. Sea Grant Special Bulletin No. 7, University of Miami. Miami, Florida. 55 pp.

Tatum, W. M. and W. C. Trimble. 1978. Monoculture and polyculture pond studies with pompano (*Trachinotus carolinus*) and penaeid shrimp (*Paneaus aztecus, P. duorarum,* and *P. setiferus*). Proceedings World Mariculture Society 9:433-446.

Trimble, W. C. 1980. Production trails for monoculture and polyculture of white shrimp (*Panaeus vannamei*) or blue shrimp (*P. stylirostris*) with Florida pompano (*Trachinotus carolinus*) in Alabama, 1978-79. Proceedings World Mariculture Society 11:44-59.

Wheeler, R. S. 1967. Experimental rearing of postlarvae brown shrimp to a marketable size in ponds. Commercial Fisheries Review 29:49-52.

Wheeler, R. S. 1968. Culture of penaeid shrimp in brackish-water ponds, 1966-67. Proceedings 23rd Annual Conference Southeastern Association Game and Fish Communications. 5 pp.

Wickins, J. F. 1972. The food value of brine shrimp, *Artemia salina L.*, to larvae of the prawn, *Palaemon serratus* Pennant. Journal of Experimental Marine Biology and Ecology 10:151-170.

Wickins, J. F. 1976. Prawn biology and culture. Oceanography and Marine Biology Annual Review 14:435-507.

Wickins, J. F. and T. W. Beard. 1978. Ministry of Agriculture. Fisheries and Food. Prawn Culture Research. Laboratory Leaflet, Ministry of Agriculture Fisheries and Food Directorate of Fisheries Research, Lowestoft (42):41 pp.

Wilkenfeld, J. S., A. L. Lawrence and F. D. Kuban. 1983. A reliable small scale expermental system for rearing penaeid shrimp larvae in a synthetic sea salt medium. Proceedings First International Biennial Conference on Warm Water Aquaculture--Crustacea. 1: (Accepted for presentation).

Wilkenfeld, J. S., J. M. Fox and A. L. Lawrence. 1981. Consumption of frozen and live *Artemia* by protozoea of *Penaeus setiferus*. Journal World Mariculture Society 12: (in press).

A REVIEW OF SPECIES SUITABLE FOR CONTAINMENT SITE CULTURE (FRESH WATER)

by
Robert R. Stickney
Department of Wildlife and Fisheries
Sciences
Texas A&M University
College Station, Texas 77843

Robert R. Stickney

ABSTRACT

Fishes and invertebrates suitable for rearing as human food in low salinity or freshwater containment sites may be either those which are relatively stenohaline freshwater forms or which are of the euryhaline marine type. In either case, they should be fast growing, tolerant to extremes in water quality, have a successful history under culture or a high potential for success, and be of high economic value. Other attributes which might be important in containment culture include ease of capture, ability to withstand crowding if cage culture were employed, and suitability for polyculture.

Among the fish species of the southern United States which appear to meet the requirements outlined, three deserve primary consideration. They are the channel catfish (*Ictalurus punctatus*), blue tilapia (*Tilapia aurea*), and red drum (*Sciaenops ocellatus*). The first two are excellent freshwater candidates for containment culture and the third is sufficiently euryhaline to survive under most salinity regimes which might occur in a containment area. Invertebrates which deserve consideration include crawfish (*Orchonectes* spp. and *Procambarus* spp.) and freshwater shrimp (*Macrobrachium rosenbergii*).

In addition to species which can be utilized for human food are a group of fishes which can be reared for sport or bait use. Among the former are striped bass (*Morone saxatilis*), largemouth bass (*Micropterus salmoides*), and sunfishes (*Lepomis* spp.).

Bait species could include minnows (e.g., *Pimephales* spp. and *Notropis* spp.) and goldfish (*Carassius auratus*).

INTRODUCTION

Freshwater containment sites could be sources of fish production through the application of standard aquaculture techniques. Because the conditions which exist in containment areas when high densities of fish are present have not been determined with any degree of sophistication, it would appear wise to utilize species for which the aquaculture potential has been well demonstrated, or to use species which appear to hold excellent promise as aquaculture candidates. Freshwater species of potential or realized aquaculture importance would, of course, be probable candidates for containment culture. Euryhaline marine species might also be suitable under certain circumstances.

In order to be eligible for consideration in containment culture, a species should meet several criteria, most of which apply to any aquaculture organism. First, it should grow sufficiently rapidly that it can be marketed within a reasonable period of time. Second, it should have sufficient economic value that will provide potential profit to the producer. Hand in hand with economics is marketability; that is, the species must be salable in local markets once it has been produced. Finally, all of the conditions required for successful culture should have been well worked out. It is probable that unique conditions in containment areas will lead to some unanticipated problems which will be much more solvable if the basics of culture have already been addressed for the target species. Among those basics are the following:

a. Successful pond and/or cage culture should have been demonstrated under commercial conditions.

b. Reproduction and juvenile rear ng should be relatively simple and under the control of the culturist.

c. The nutritional requirements of the animal should be sufficiently known that adequate diets for the promotion of rapid growth with good food conversion efficiency can be formulated.

d. Prepared feeds must be readily accepted.

e. The tolerances for water quality of the animal should be well documented and sufficiently broad that the fish can be expected to withstand conditions known to occur in containment areas.

f. Harvesting should be relatively simple and efficient.

The list is not exhaustive by any means, but should provide the potential containment culturist with some goals.

Among fishes which can be reared as human food, two freshwater species which are found in the southern United States meet all or most of the criteria presented. They are the channel catfish (*Ictalurus punctatus*) and tilapia (*Tilapia* spp.).

A third fish which deserves examination as a potential candidate in containment culture is a marine species with exhibits a remarkable capacity to adapt to low salinity water. That fish is the red drum (*Sciaenops ocellatus*). The first two species listed are widely grown in aquaculture. Channel catfish culture is largely restricted to the United States, while tilapia are popular throughout the tropical world. Red drum, on the other hand, is a fish which appears to hold excellent potential for culture in marine, brackish, and freshwater systems.

Among the freshwater invertebrates which might be considered for aquaculture in containment sites, two groups which are used directly as human food appear to hold promise. Those are the crawfish (genera *Orchonectes* and *Procambarus*) and freshwater shrimp (*Macrobrachium rosenbergii*). The latter is not considered in the following section since there are presently no commercial hatcheries in the continental United States to provide postlarvae for stocking. Once a dependable supply of postlarval freshwater shrimp is available and a few other problems associated with the culture of that animal are worked out, consideration of them in dredged material containment areas might be more appropriate.

Various sport and bait species could provide potential as aquaculture candidates in dredged material containment areas. Some of them are identified at the end of this paper. There appears to be some potential for fee fishing in containment areas and that prospect, along with utilization of a particular area for waterfowl management and subsequent hunting, seems to be an alternative to simple aquaculture.

CHANNEL CATFISH

The history of channel catfish culture in the United States is well documented in the literature. Channel catfish are widely produced in the southern United States, in California, and in isolated areas outside of those regions (Figure 1). Furthermore, all of the culture requirements of the species are readily controlled by aquaculturists (Stickney 1979). The species conforms to the six criteria outlined above, with the possible exception that water quality in containment areas may be sub-optimum under certain circumstances. A careful evaluation of temporal, including both diurnal and seasonal, variations in non-conservative water quality variables such as dissolved oxygen, pH, ammonia, and nitrite nitrogen would be required prior to implementation of commercial culture.

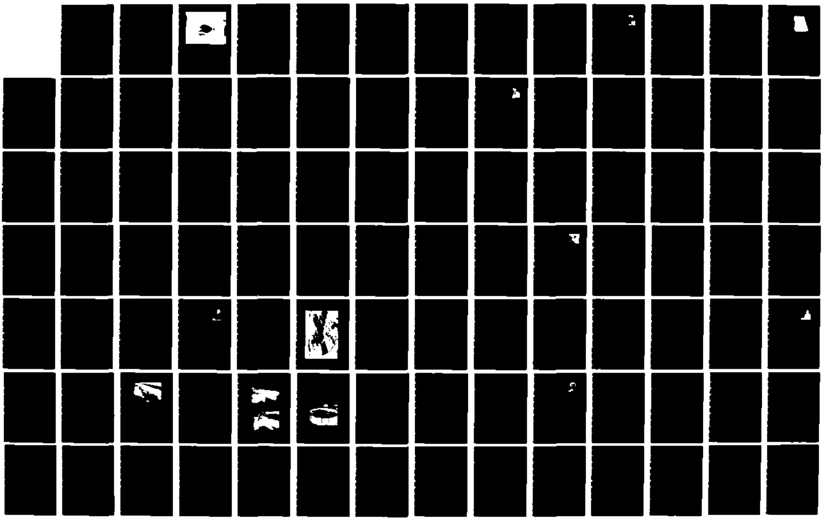
Channel catfish can be effectively reared in cages or net pens in situations where harvest from a containment area might be difficult. A significant amount of work has been conducted with channel catfish in cages, though little commercial cage culture is currently being practiced.

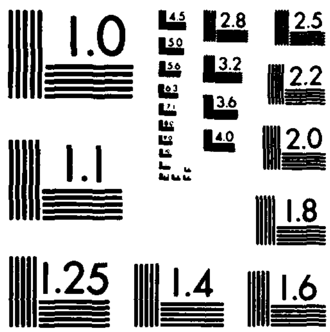
Production of channel catfish varies as a function of culture intensity with the accepted average value for pond culture being in the vicinity of 3,000 kg/ha/yr (currently, many Mississippi catfish farmers are producing in excess of 4,000 kg/ha/yr). Research would be required to determine optimum stocking densities of catfish in containment areas and production would have to be followed so that the levels obtained could be compared with those from typical culture ponds.

Figure 1. Channel catfish broodstock are selected for stocking into brood ponds prior to the spawning season

AD-A135 075 DREDGING OPERATIONS TECHNICAL SUPPORT PROGRAM AQUACULTURE IN DREDGED MATE..(U) ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS ENVIR.. 2/3

UNCLASSIFIED J HOMZIAK ET AL. OCT 83 WES/MP/D-83-2 F/G 13/2 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Potential problem areas relative not only to channel catfish culture, but also the culture of other species in containment areas, include the following:

a. Direct mortality from contaminants in the soils of the containment areas.

b. Accumulation of toxicants or potential toxicants in the flesh of the fish during culture and passage of those toxicants to the consumer.

c. Presence of competitors and predators in the containment area.

d. Presence of pathogenic organisms in the containment area.

e. Poaching and vandalism.

f. Source and quality of water when addition is required to replace evaporative and/or seepage losses.

g. Ability to drain the containment area at the time of harvest if the fish are allowed to roam freely.

Each of these problems will require careful evaluation, in some cases through research programs, before commercial culture can be advocated.

TILAPIA

Tilapia (Figure 2) are native to North Africa and the Middle East. They have been introduced throughout the tropical world into aquaculture and are well known and widely accepted in most countries. While tens of species might hold potential in aquaculture, only a handful are currently being reared commercially or under subsistence culture conditions around the world. Two species of tilapia are currently approved for use in Texas: the blue tilapia (*Tilapia aurea*) and the mossambique tilapia (*T. mossambica*). The status of these and other species may be different in other states, but, in general, tilapia are available throughout much of the south.

Tilapia meet four of the six requirements outlined in the Introduction. At present there is only limited information on the nutritional requirements of tilapia, though they readily accept prepared feeds formulated for channel catfish and their growth and food conversion efficiencies on such diets are excellent. Thus, rearing can be economically accomplished without complete information on nutritional requirements of the fish. The other area in which problems exist involves harvest. Tilapia are noted for being able to bury in soft sediments and are able to avoid capture with various types of nets. Trapping, electroshocking, and other standard harvest methods are also largely ineffective on these fish. Cage culture would provide one means of circumventing the harvesting problem, particularly in containment areas which could not be readily drained.

Tilapia have an amazing ability to tolerate poor water quality, with one major exception. They cannot survive at temperatures below 10 to 12°C for more than a few hours. When exposed to temperatures approaching lethal, their normally superior disease resistance breaks down and they become susceptible to such normally incidental problems as infection with the fungus *Saprolegnia*, not to mention a host of bacterial and parasitic infestations

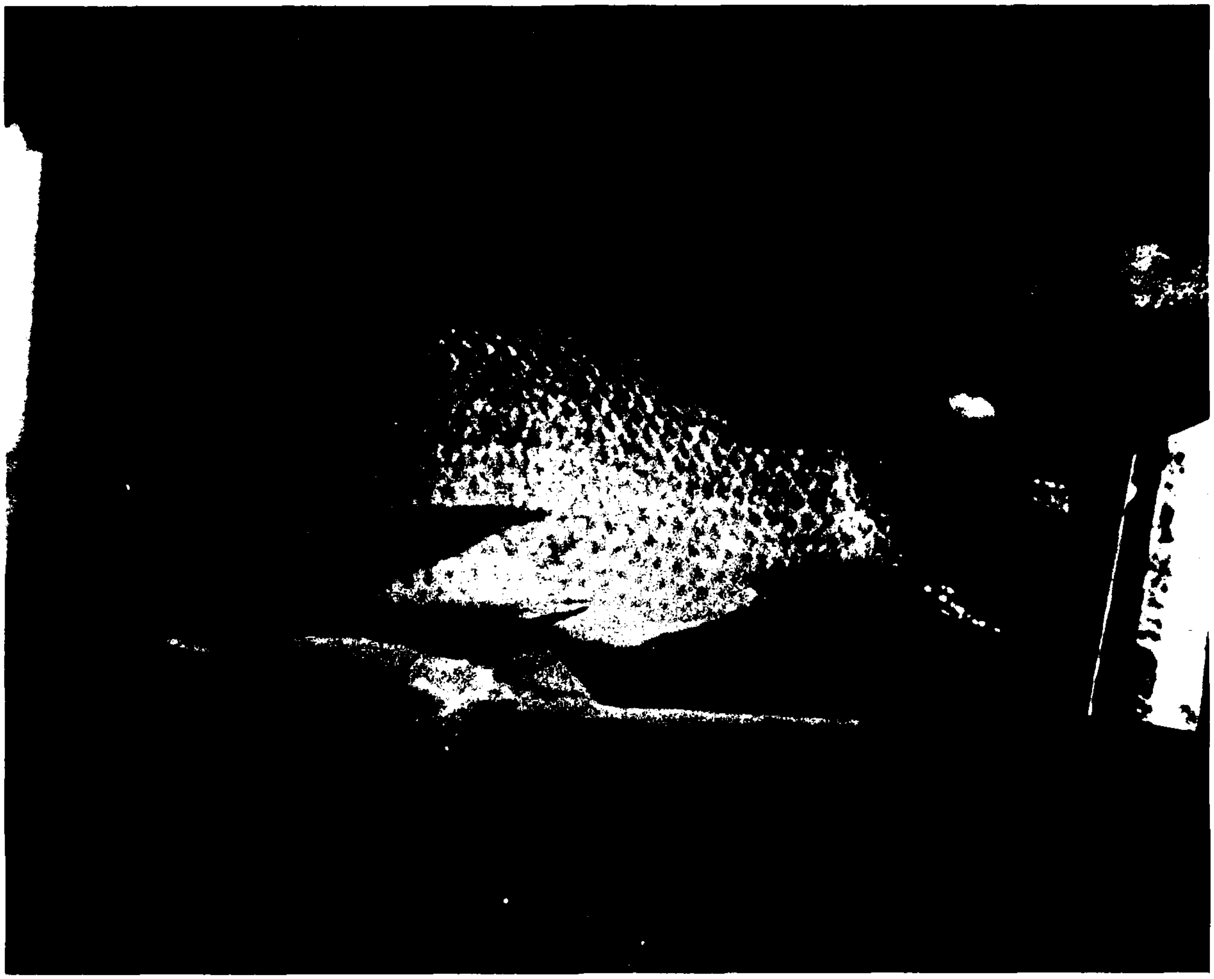


Figure 2. *Tilapia aurea* exhibits some of the most desirable characteristics of the tilapia species presently under culture around the world

which commonly occur. Because of their intolerance to cold, it would be necessary to harvest the fish prior to the onset of winter. The only exception would be in extreme southern portions of Florida or Texas where overwintering populations have been established.

Tilapia are broadly euryhaline. Most species can be placed directly from fresh water into seawater without damage. This characteristic makes them an ideal candidate for containment culture in either freshwater or saltwater conditions as well as in instances where salinity might change from time to time.

A typical strategy might be to overwinter sufficient broodfish to provide offspring for stocking in the following spring. Those offspring would be reared in the containment area until fall and would be marketed after another group of broodfish was selected. The major problem involved with that scheme is that the fish may be of questionable market size by the end of the first growing season. That problem will become increasingly evident

as latitude of the culture facilities increased. A desirable market-sized animal should be near 450 g. The rearing of 250-g animals within a growing season is readily possible, and, with good management, somewhat larger sizes can be produced. Reaching the 450-g goal may, however, be difficult except during an unusually long growing season or in the most southern portions of the country. Year-round culture would, of course, be possible in Hawaii.

The second noteworthy problem which exists with tilapia involves their tendency to overpopulate ponds. This is more of a problem with *T. mossambica* than it is with some of the other species. *Tilapia mossambica* can begin reproducing at the age of three months and while they may produce only about 200 eggs at that age, overpopulation and resultant stunting can quickly occur. *Tilapia aurea, T. nilotica,* and others may not begin to reproduce until six months of age. They will be larger at first spawning than *T. mossambica* and consequently will produce more eggs per female, but the competitive advantage of the adults for food coupled with the fact that the end of the growing season is approaching may mitigate against stunting.

Females, which shunt a great deal of food energy into egg production once they begin to become sexually mature, do not grow as fast as males. Also, in most species the females mouth brood the young. Thus, the female may be unable to eat for a period of two weeks or so out of each 30-day spawning cycle (the eggs are maintained in the mouth during incubation and until yolk-sac absorption). Some of the techniques which have been utilized to overcome the problem are:

a. Stock only males. This can be accomplished by

(1) hand-sexing the fish once they become large enough.

(2) producing all-male stock through selective hybridization.

(3) feeding male hormones to newly hatched fry and convert all of them to males.

b. Stock the fish in cages so that the gametes are lost during spawning.

c. Stock a predator which will consume the fry without affecting the initially planted stock.

These techniques have been reviewed by Ballarin and Hatton (1979) and have all worked successfully in a variety of culture situations. Any technique which does not utilize all-male populations will lead to a dichotomy in mean size at harvest due to the differential growth rates of the two sexes. It is doubtful that many marketable females can be reared within a single season in the continental United States.

One caution in the use of all-male populations is necessary. The culturist must maintain some females or there will be no reproduction in the spring to provide fingerlings for stocking. At present, while there are a small number of tilapia producers in the United States who will sell fingerlings, the cost may be prohibitive, particularly when one considers the general ease with which reproduction can be achieved.

Tilapia are exotic fishes; therefore, like certain penaeid shrimp and other aquaculture organisms, some consideration of their potential impact on natural productivity, should they escape, must be taken into account in any region where they are considered for culture. Tilapia were introduced into

the United States in the 1960's or before and have become established in certain areas (Hawaii, Texas, and Florida). Their presence has led to a certain amount of controversy in some regions and it may be necessary to ensure that no escape from an aquaculture facility is likely in order to satisfy environmentalists concerned with their potential impact on natural fish stocks. Measures can be taken to preclude escape of tilapia into natural waters from aquaculture facilities established on dredged material containment areas. In regions where winter water temperatures fall below 8-10°C, the chances of tilapia surviving a winter in nature are very poor unless individual fish are able to find a source of warmer water in which to sustain themselves until the spring.

RED DRUM

Red drum appear to have excellent aquaculture potential. What little is known about them appears good from the standpoint of desirability for culture. They will survive in fresh water, though it is best if that water is quite hard. A small amount of salt appears to be effective in protecting their disease resistance (Davis and Stickney 1982).

Some pond culture has been accomplished with red drum, though there is really little known about optimum stocking densities. The fish grow well in intensive tank culture and should survive and grow in cages.

Reproduction can be achieved under controlled conditions but there is currently no commercial source of fingerlings. The average culturist would not be able to establish a hatchery for red drum unless that person were willing to make a considerable investment. Interest in the species is currently on the increase, however, and it can be expected that fingerlings will become commercially available in the foreseeable future, particularly as research successes continue and are made known to the aquaculture community.

Virtually no nutritional information on red drum has been obtained, but like tilapia, *S. ocellatus* will consume and grow well on commercial catfish and trout feeds. In fact, tank studies indicate that their growth may be as good or better than either channel catfish or tilapia.

Red drum appear to have about the same tolerance for water quality as catfish, with the exception that red drum are much more euryhaline. *Sciaenops ocellatus* may not be able to tolerate the dissolved oxygen and ammonia conditions which can be survived by tilapia; red drum do not succumb to low temperature over the normal range which occurs along the Gulf of Mexico coast of the United States except when drastic and rapid reductions occur.

Harvesting of red drum by seines would have about the same effectiveness as that which is achieved with channel catfish. The fish would, thus, be much more catchable than tilapia.

Marketing would be no problem with respect to red drum. The fish could be dressed in coastal fish processing plants or the producer could establish a small processing facility. A commercial fishing ban is currently in effect

on *S. ocellatus* in Texas, though maricultured red drum have been exempted from the ban.

CRAWFISH

Crawfish culture has developed in recent years into a relatively large commercial industry. At present, there are approximately 32,000 ha of crawfish culture ongoing in Louisiana (Robert Romaire, personal communication), 2,000 ha or more in Texas (James T. Davis, personal communication), and a small amount in South Carolina (Paul Sandifer, personal communication). The appeal for crawfish appears to be growing, not only in areas where they have traditionally been consumed, but also in other regions of the United States.

Crawfish can be reared in shallow ponds. In fact, many rice fields in Louisiana and other states have been converted to crawfish ponds. Thus, containments areas which have been filled or nearly filled might provide suitable habitat for crawfish culture. In addition, harvesting of crawfish (which is routinely accomplished by trapping) might be more simple in confinement areas having uneven bottoms than would the harvest of fish or freshwater shrimp (usually harvested with seines).

While there is virtually no information available on the nutritional requirements of crawfish, that is not a detriment to commercial culture. Crawfish ponds are planted with rice or some other suitable forage plant prior to stocking and the animals are not provided with any other type of food during the growing season. Even so, production rates of several hundred to over 1,000 kg/ha/yr have been routinely achieved from crawfish ponds.

OTHER SPECIES

If conditions in containment areas preclude the culture of fish for direct human consumption, the production of one or more species of bait minnows (*Pimephales* spp. or *Notropus* spp.) or goldfish (*Carassius auratus*) might be possible. The techniques for production of such species have been well developed. Another alternative might be the use of containment areas for the production of such sport fish as largemouth bass (*Micropterus salmoides*) or one or more of the sunfishes (*Lepomis* spp.) which are often used as forage in farm pond stocking strategies.

A considerable amount of knowledge currently exists with respect to the culture of striped bass (*Morone saxatilis*) and that species could also be considered for rearing in containment areas. In colder climates than that which exists along the Gulf of Mexico coast, it might be possible to rear such species as yellow perch (*Perca flavescens*) in containment areas. Under certain circumstances salmonids might do acceptably well in containment areas, but their demands for extremely high water quality might be excessive for the environmental conditions that can be expected. Winter cage culture of salmonids in southern containment areas could, however, hold some potential.

The decision on which species to produce should be made, in any case,

on the particular dredged material containment site selected. Preliminary analyses of soil and water will have a bearing on that decision, as will the regional preferences of consumers and the location of the site relative to retail markets. In the final analysis, a variety of freshwater species are suitable fcr culture in dredged material containment sites. What remains to be determined is how production in such sites compares with that in ponds or other aquaculture facilities designed specifically for the culture of those species.

LITERATURE CITED

Ballarin, J. D., and Hatton, J. P. 1979. "Tilapia: A Guide to Their Biology and Culture in Africa," University of Stirling, Stirling, Scotland.

Davis, S., and Stickney, R. R. 1982. "Growth and Survival of Fingerling Redfish (*Sciaenops ocellatus*) in Low Salinity and Freshwater Systems," Proceedings of the 1982 Fish Farming Conference and Annual Convention, Fish Farmers of Texas, Texas A&M University, College Station, Tex., pp 36-41.

Stickney, R. R. 1979. Principles of Warmwater Aquaculture, Wiley-Interscience, New York.

QUESTIONS AND ANSWERS

Jesse Pfeiffer: Would the redfish be applicable to polyculture?

Dr. Stickney: We've cultured it in the presence of catfish without any problem. It's a predator; it's going to be tough on a shrimp population, but it should be approriate with other fishes if the redfish is not larger than the other species. If you stock two sizes of redfish, the large ones will actually choke themselves to death trying to swallow a smaller fish. So you want to be judicious. I'd put them as the smaller of the two fishes if I had them in a polyculture situation.

Roger Mann: There's one very strong negative comment that I'd like to make about tilapia, of which I'm sure you're aware: the potential for escapement. There's a gentleman at Florida Atlantic University named Walter Courtney who's looked at blue tilapia in some of the lakes in nothern Florida. From one or two introductions of individual animals, this animal gets up to about 97% of the biomass of all fish in the lakes in under two years. About the only thing that they've found that can control them are spills from the citrus plants. Because tilapia is so tolerant of seawater conditions, these animals escape from fresh or brackish water ponds into saltwater and actually breed there. If any of you are lucky enough to go to Hawaii in the next few years, I suggest you visit Honolulu Harbor and look at the fish that are shoaling around under the boats. They're tilapia, and they're essentially an introduced species that escaped from freshwater impoundments into the harbor. If they can do that in a place like Hawaii, think of what they're going to do to your local ecosystems and what that's going to do to your permitting procedure.

Dr. Stickney: What you say is true. I'm remiss for not bringing that up. The fish has been in Texas since the 1960's. It's been along the gulf coast. There's only one place I'm aware of that it's invaded saltwater and that's in parts of Tampa Bay. And that's *Tilapia milanotherun*, I believe. The fish were illegal here until about two years ago when Parks and Wildlife decided that they could no longer avoid the fact that tilapia had established reproducing populations in power plant lakes. In the Rio Grande Valley, they do overwinter. But, as far as I know, there's no competition in the saltwater environment of the gulf coast, aside from Tampa Bay.

Durwood Dugger: Three points. First, I'd like to point out that there's a tremendous difference between strains of the two major tilapia species that we were allowed to work with in Texas, *Tilapia aurea* and *T. mossambica*. As you said, *T. aurea* is in the Rio Grande Valley. As far as we can tell, there hasn't been any overpopulation there. There are a number, but they're mixed with carp and catfish and bass, and they seem to get along fine.

Dr. Stickney: The only problem we've ever had is in Lake Trinidad where we had 3,000 pounds per acre standing crop of total fish, 2,000 pounds of which were tilapia. They shut the power plant down in the winter of 1976-77 and killed six million fish in a matter of a couple of days and wiped out that population.

Durwood Dugger: That was in a natural environment.

Dr. Stickney: That was in an environment that looked like a highly fertilized pond. Water was pea soup green 12 months of the year. In Falcon reservoir the tilapia populations have never gotten extremely large because they are in clear water, their food supply is limited, and the predators are keeping them cropped.

Durwood Dugger: The other point is, we will be opening a *Macrobrachium* hatchery for our use as well as for commercial purposes this January in south Texas, and we'll have a production capacity of between two and four million a month. So there will be a U. S. hatchery available for people who want the stock.

Dr. Stickney: We get calls about that nearly every week, someone wanting to buy *Macrobrachium*.

Durwood Dugger: Usually two dozen.

Dr. Stickney: Well, that's the problem. I had somebody call me one time who wanted one catfish.

Henry Hildebrand: Tilapia invaded the Alvarado Lagoon, and it apparently had a very great effect there. It depends on whether you talk to aquaculture people or whether you talk to folks dealing with wild populations as to how much damage it has done. But they blame considerable declines in the robollo population in that area on tilapia. I understand the French have done some rather extensive work showing very great damage in the estuaries of West Africa.

Jack Parker, Laguna Madre Shrimp Farms: What's the lower temperature limit for growth on redfish?

Dr. Stickney: The literature says they'll go down to 2-5°C. But they won't grow at those temperatures. I don't know where they stop growing.

Jack Parker: They have a pretty low tolerance?

Dr. Stickney: They have a fairly broad tolerance in fresh water. Some of the people say they've lost them when the temperature was still above freezing. One of the first things we need to find out is how low a temperature they can tolerate in fresh water. They may have a poorer tolerance in fresh than salt.

Jack Parker: Could you culture them in cages?

Dr. Stickney: I think you could. We can culture them very easily in tanks. The amount of experience people have had with this species is insignificant.

MARICULTURE POTENTIAL ALONG THE NORTHERN GULF COAST

by
Walter M. Tatum
Marine Resources Division
Alabama Department of Conservation
and Natural Resources
Claude Peteet Mariculture Center
Gulf Shores, Alabama 36542

Walter M. Tatum

ABSTRACT

The concept of mariculture is based on the simple premise of controlling environmental parameters which are conducive to fish husbandry, thereby creating an environment capable of efficiently and dependably producing a quality product on a sustained level. The ability to sell the product at a price sufficient to produce profit is a major goal of the mariculturist.

Species on which mariculture experiments have been conducted in Alabama either command a high price for food or bait, represent depressed natural fisheries, can be marketed at a time when stocks from the wild are low, or provide a unique produce to the area.

Production experiments with *Fundulus grandis*, a highly sought after live bait minnow in coastal areas, have produced successive crops of 603, 673, and 714 kg/ha in one growing season at Alabama's Claude Peteet Mariculture Center (CPMC). Polyculture experiments with penaeid shrimp and pompano have produced combined weights of 1023 kg/ha (437 kg/ha pompono and 586 kg/ha shrimp) in less than 150 production days. Winter culture experiments with rainbow trout in brackish water ponds have produced 815 kg/ha in under 100 production days. Experiments with red snapper have demonstrated the ability of juveniles to adapt to pond environments and produce gains on commercial fish feeds. Red snapper and vermilion snapper have been successfully spawned at CPMC.

The potential of mariculture in Alabama is promising, but fiscal restraints for research could thwart the development of this industry. The low cost of land associated with dredged material containment sites coupled with the protection to facilities afforded by the gained elevation can offset some fiscal restraints which now exist.

INTRODUCTION

The concept of mariculture, or aquaculture in a marine environment, is based on the simple premise of controlling environmental parameters which are conducive to fish husbandry, thereby creating an environment capable of efficiently producing a quality product at dependable levels and knowledge to dependably duplicate production levels year after year. The concept is indeed simple, but in application requires a multidiscipline approach which few government agencies and private enterprises can afford to adequately finance.

A successful operation is not necessarily one that grows large amounts of a particular product and an unsuccessful operation is not necessarily one that produces small amounts of a particular product. The bottom line of success, as presently viewed, is the ability to sell the product at a price which will offset production costs and provide sufficient profit for future incentive. Production of 4,000 kg/ha of a product that won't sell is not successful and production of 300 kg/ha of a product that brings $30.00/kg may well be considered successful. In his keynote address to the World Mariculture Society in January 1975, P. Korringa of the Netherlands Institute for Fishery Investigations spoke on the economics of mariculture. He stated that the value of a mariculture-produced product, of which considerable quantities are also caught in the wild, would be the same as paid to fishermen for that wild caught product, thus limiting somewhat the potential of the mariculture value.

The potential significance of mariculture-produced fishery stocks is greater today than ever before as worldwide fishery production from the seas has become limited (Tiews 1977) and is no longer meeting demand (Donaldson 1978). Donaldson (1978) provided four common facts that were present at successful mariculture ventures throughout the world: (a) the life history of the animal to be cultured was available, (b) seed from selected brood stock was used, (c) food for all stages of the growing animals was available, and (d) a market demand for the crop where it can be sold at a profit was already developed or was developing.

The Claude Peteet Mariculture Center, a research facility operated by the Marine Resources Division, Alabama Department of Conservation and Natural Resources, began conducting marine fish and shellfish culture experiments in 1972. The culture facility was established on a 40-acre tract of land in Baldwin County, Alabama, immediately adjacent to a U. S. Army Corps of Engineers dredged material containment site. The containment site was created in 1936 when the Gulf Intracoastal Waterway connecting Mobile Bay and Perdido Bay was constructed. Soils within the 40-acre tract of land are Scranton, Plummer, and Raines, all associated with Coastal Plain and Flatwood Ranges. The soils are typically poorly drained with slopes of 5% and less containing

coarse sand subbases. The texture of the soil types severely limits their usefullness for either agriculture or homesites, thereby creating an opportunity for mariculture in a noncompetitive land use framework. The low cost of land associated with dredged material containment sites, coupled with the protection to facilities afforded by the gained elevation, can offset some fiscal restraints which now exist.

Species on which mariculture experiments have been conducted either command a high market price for food or bait, represent depressed natural fisheries, can be marketed at a time when stocks from the wild are low, or provide a unique product to the area. The following discussion summarizes mariculture research at Claude Peteet Mariculture Center and addresses the potential development of commercial mariculture operations by species in coastal Alabama.

MARICULTURE POTENTIAL BY SPECIES

Bull minnow (*Fundulus grandis*)

Bull minnows have historically been used as live bait by recreational fishermen in coastal Alabama (Tatum and Trimble 1977) and the market was supplied by individuals who trapped live bull minnows from local tidal and marsh pools. Local live bait dealers in the coastal area have witnessed the fact that nature does not meet the demand for the product. This fact encouraged our agency to explore the adaptability of the species to a monoculture, brackish water pond environment.

Initial culture trials with bull minnows began in 1975 with the establishment of the adaptability of the species to both a pond environment and artificial feed. Refinement of culture techniques followed during the years 1976-1981 with each culture year addressing unresolved problems previously identified. The culmination of bull minnow culture, even after seven years of intensive research, has not been reached; however, research has sufficiently advanced to a point that dependable culture methods for producing commercial quantities of bull minnows can be recommended (Tatum et al. 1982).

The recommended culture technique is three phase in application: spawning ponds, hatching ponds, and grow-out ponds. The technique is very effective in procuring maximum numbers of fertilized eggs from the brooders; efficiently providing high quality, disease-free hatchlings from the eggs; and producing multiple crops of marketable size bull minnows for the live bait market.

Brood ponds are stocked with adult bull minnows at a rate of 25,000/ha with a ratio of two females to one male. When water temperature reaches 20°C in the brood pond, Spanish moss spawning mats (Figure 1) are placed around the margin of the pond. Egg-ladened mats are then transferred to hatch ponds where hatching and growth of fry occur. When hatchlings reach 0.5 g, they are transferred to production or grow-out ponds and placed on a daily feeding regime until reaching marketable size. The prolonged bull minnow growing season in south Alabama, coupled with the rapid growth of the bull minnows to marketable size, permits the culture and harvest of three consecutive marketable crops. The total weight of each crop as well as

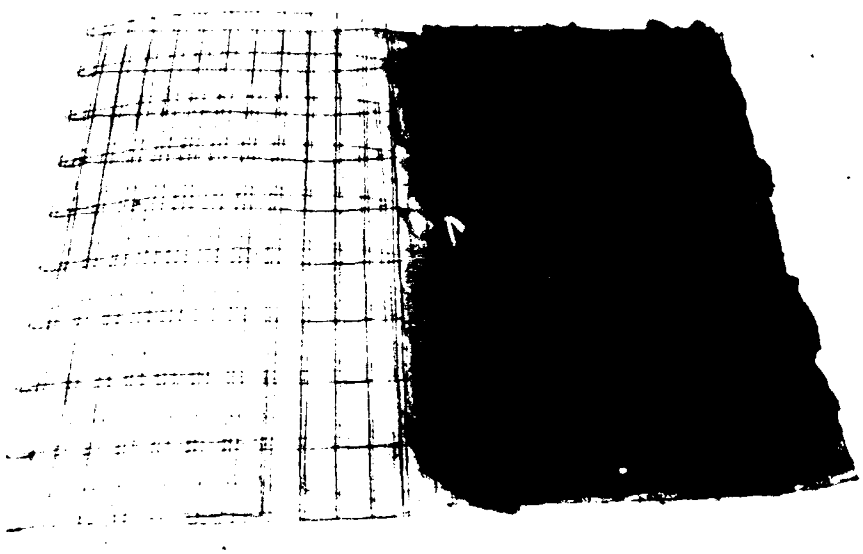


Figure 1. Spawning mats constructed of vinyl-coated welded wire and Spanish moss have proven to be the most successful spawning media for bull minnows

length of culture depends on the stocking rate. At a stocking rate of 250,000 bull minnows/ha, successive crops of 603, 673, and 714 kg/ha have been produced at approximate 55-day intervals, a combined annual production of 1989 kg/ha. This total production represents over 625,000 marketable size minnows with a current wholesale value of $46,875.

Polyculture of pompano
(*Trachinotus carolinus*) and penaeid shrimp

Polyculture is a husbandry technique which involves the culture of more than one species in a single body of water. The strategy in selecting species for polyculture should ensure first the compatibility of the various species in a single environment and next selecting species which occupy different niches within the single body of water.

Polyculture of fish and penaeid shrimp is a technique centuries old in Southeast Asia, but virtually nonexistent in the United States (Tatum and Trimble 1978). Prior to research at Claude Peteet Mariculture Center, no polyculture studies had been conducted with pompano and penaeid shrimp. The two species were selected for studies in Alabama because: (a) both species are highly sought by consumers and bring premium prices; (b) each species occupies a separate niche within a single environment (shrimp--demersal and pompano--pelagic); and (c) although pompano will prey on shrimp, the pompano mouth is very small and, through manipulation at stocking, shrimp can grow faster than the pompano mouth thus minimizing predation.

Five shrimp species have been tested in a polyculture environment with pompano: pink shrimp (*P. duorarum*), brown shrimp (*P. aztecus*), white shrimp (*P. setiferus*), all indigeneous to the Gulf of Mexico, and two exotic species, *P. vannamei* and *P. stylirostris*. Three shrimp stocking procedures have been

utilized in polyculture experiments during three successive years (1975-1977), each season demonstrating greater shrimp survival than the previous. Table 1 presents production data achieved during each of these separate techniques (Trials 1-5). Trial 1 demonstrated the low survival of shrimp when stocked as postlarvae into a pond containing fingerling pompano (shrimp survival 2% and production of 21 kg/ha). Trial 2 demonstrated an intermediate shrimp survival when pompano are stocked 25 days after postlarval shrimp (shrimp survival 30% and production of 150 kg/ha). Trial 3 demonstrated the favorable shrimp survival when shrimp were first reared in a nursery pond for 30 days before stocking into pompano pond (shrimp survival 53% and total production of 222 kg/ha). Trials 4 and 5, utilizing *P. vannamei* and *P. stylirostris*, respectively, utilized the same technique as Trial 3 and produced shrimp survival and biomasses of 90% (252 kg/ha) and 63% (736 kg/ha), respectively.

Obviously, techniques were being refined during each successive culture year, with the best total production of pompano and shrimp occurring with *P. stylirostris* during Trial 5 when 549 kg/ha pompano and 736 kg/ha of shrimp, a combined total of 1285 kg/ha, were produced.

Ideal conditions in a polyculture environment enable the second species in the body of water to exhibit gains from the wastes from the primary species. These conditions are met in our polyculture work with shrimp and pompano by providing feed based on the pompano biomass, with the shrimp acquiring their sustenance from uneaten feed, fish wastes, and other detrital products which accumulate in the pond.

Shrimp monoculture

Table 2 summarizes production data from shrimp monoculture studies with four species of penaeid shrimp. All studies involved the initial rearing in nursery ponds prior to stocking into production ponds. Survival of all four species is acceptable, but production has been dependably acceptable for only two species, *P. setiferus* and *P. stylirostris*. Ironically, the record production from a monoculture pond at CPMC (2331 kg/ha) was achieved from *P. vannamei*, the species which produced the least production demonstrated in Table 2. This production came from a nursery pond which received feed for 140 days and had been partially harvested for stocking production ponds. Postlarvae *P. vannamei* have not been available since 1978 and, therefore, no additional studies have been conducted on this very promising species.

The principal problems associated with shrimp culture in Alabama are: (a) the Gulf of Mexico produces more shrimp for the U. S. market than any other region in the United States and mariculture-produced shrimp will have to compete with an extremely competitive natural fishery; (b) postlarval shrimp are available only in limited numbers at the present time;* (c) the efficiency of converting pounds of feed to pounds of shrimp is higher than it should be, suggesting poor quality feed, or inadequate feeding procedures; and (d) insufficient pond culture research exist aimed at dependably duplicating peak production.

The first of these problems can be partially solved through proper timing of the shrimp harvest and marketing. Shrimp can be held in a pond for a

* In the spring of 1982 the only known source of postlarve shrimp was Shrimp Culture, Inc., Sugarloaf Key, Florida.

Table 1

Summary of Pond Studies on Polyculture of Pompano (P) and Penaeid Shrimp (S) at CPMC 1975-1979 (Tatum and Trimble 1978; Trimble 1980)

	Stocking Data						Harvest Data								
	Mean Wt (g)		Density (No/ha)		Prod. Days		Mean Wt (g)		Kg/ha			Surv.		Feed Conver.	
Shrimp Species	P	S	P	S	P	S	P	S	P	S	Total	P	S	P	S
Trial 1															
Pink shrimp	0.2	0.003	10,412	31,250	182	155	162	26.6	668	21	689	40	2	2.5	2.4
Trial 2															
Brown shrimp	0.6	3.3	8,750	31,250	128	153	124	16.0	352	150	502	34	30	3.1	2.1
Trial 3															
White shrimp	0.5	0.6	10,412	31,250	146	151	184	13.5	593	222	815	30	53	3.5	2.6
Trial 4															
P. vannamei	1.5	1.2	4,925	25,000	36	62	14	11.2	13	252	265	21	90		0.9
Trial 5															
P. stylirostris	5.1	1.8	10,000	82,813	105	148	75	14.1	549	736	1,285	74	63		3.0

Table 2

Summary of Pond Studies on Monoculture of Penaeid Shrimp at CPMC (1977-1979)

	Stocking Data				Harvest Data				
					Weight (g) of Shrimp				
Species	Date Stocked	Mean Weight (g)	Prod. Days	Stocking Rate (No/ha)	Mean	Range	Kg/ha	Surv.	Feed Conversion
P. aztecus	5-20-77	0.7	81	62,500	7.6	1.8 - 14.7	349	73	3.9
P. setiferus	8-10-77	0.6	75	62,500	10.0	3.5 - 17.8	600	96	2.3
P. vannamei	6-29-78	1.2	63	25,000	11.9	3.9 - 19.7	193	63	3.8
P. stylirostris	6-11-79	1.8	149	82,813	16.0	2.2 - 33.2	904	70	4.5

reasonable time to achieve an advantageous market price. If one holds harvest until late fall, a period in which natural production for the fresh shrimp market is usually low, a good price for the product can be obtained. Similarly, good production from a mariculture facility during the cyclic low production years in the natural fishery may also be advantageous.

All of the other problem areas are being addressed by research along the Gulf of Mexico and research money, time, and patience will of necessity precede their resolve.

Rainbow trout (*Salmo gairdneri*)

All species, except red drum and bull minnows, that have been cultured at CPMC demonstrate winter kills when retained in shallow, brackish water ponds. Winter temperatures sufficiently low to kill pompano, shrimp, spotted seatrout, and red snapper normally occur in coastal Alabama by mid-November and normally last until around mid-March. Tatum (1973) demonstrated the adaptability of rainbow trout, *Salmo gairdneri*, to brackish water culture as well as their ability to produce positive gain during the winter months in coastal Alabama.

Initial winter production trials were conducted in cages in Dauphin Island Bay, Alabama, with experiments initiating in fall (November 1971) immediately following harvest of pompano. During a 120-day culture period, 99 kg of rainbow trout (mean weight 318 g/trout) was produced per cubic meter of cage volume from fingerlings whose initial weight was 93.8 g.

Subsequent pond studies with rainbow trout at CPMC have produced yields as high as 1025 kg/ha (mean size of individual trout - 272 g) with feed conversion ratios of 1.9 (Tatum 1976a). Preliminary results of culture studies during fall and winter 1980-1981 demonstrated the ability to grow 27-g fingerlings to a marketable size of 136 g in approximately 100 culture days with a survival rate of over 70%.

Production trials have demonstrated the ability to produce high quality gains at a brackish water culture facility during winter months in coastal Alabama. The combined production of pompano and shrimp (spring and summer) and rainbow trout (fall and winter) are therefore available to provide commercial gains on a year-round schedule.

Red snapper (*Lutjanus campechanus*)

Natural stocks of red snapper have shown definite declining catch gulfwide since 1966 (GMFMC Reef Fish Management Plan*). Minton et al. (in press) stated that the red snapper ranked fourth in the gulf as the most sought after fish by recreational anglers, and ranked first by charter fishing boats. Increasing fishing pressure, high value, and declining red snapper stocks have suggested future mariculture prospects for the species.

Initial culture trials at CPMC with red snapper commenced in August 1975 when adults were trapped in the Gulf of Mexico and successfully transported to the mariculture center (Tatum 1976b). During that same year, juvenile snapper (37 g each) were trapped in the estuarine area of Baldwin County, stocked into brackish water ponds at CPMC, and feeding trials initiated. Potential brooders were examined for the presence of viable

* Gulf of Mexico Fishery Management Council (1979).

gametes with the males showing positive signs of ripeness and the females demonstrating either spent or sexually immature signs.

Juvenile red snapper stocked into ponds in October 1976 adapted to commercial feeds and demonstrated growth during the culture period. Initially stocked at 27 g each on 5 October, growth to 59 g each was achieved by 10 December. A cold front plumeting water temperature to 7.2 - 8.9°C killed the juveniles on 10 December (Tatum and Trimble 1977).

During the summer of 1978 red snapper were again successfully collected from the Gulf of Mexico and transported to CPMC. Two female snapper were injected with human chorionic gonadotropin (HCG) at levels of 0.55 IU/gram of body weight. One female died following the injection and the other discharged eggs into the vat before a viable male could be obtained.

During July of both 1980 and 1981, snapper were collected from the Gulf of Mexico from water depths of from 9.1 - 28 m, the air bladders were deflated with hypodermic needles, and the fish were transported to CPMC. Gametes were sampled with catheter tubes and eggs staged to determine proper timing for administering HCG. Following initial injections of HCG at 1.1 IU/g of body weight, egg samples were taken to determine egg development and proper stripping time (Minton et al. in press).

Successful ovulation, fertilization, and hatching of red snapper were achieved in both 1980 and 1981 and larval snapper retained until 5 days posthatch. Several food items were offered to the young snapper but to date no food has been adequate to sustain the larvae beyond 5 days posthatch.

Additional research has been scheduled to address needed food items for larval snapper and, hopefully, some of the culture problems will be solved in the near future.

Vermilion snapper
(*Rhomboplites aurorubens*)

During the summer of 1982, vermilion snapper were taken from an artificial reef in the Gulf of Mexico in approximately 28 m of water off Orange Beach, Baldwin County, Alabama. The fish were taken by hook and line, placed in an oxygenated fish transport tank, the expanded air bladder equalized with a hypodermic needle, and the fish transported to CPMC. Ovulation was induced both with injections of HCG and temperature manipulation. Vermilion snapper larvae were offered a variety of cultured foods including oyster larvae, size graded and ungraded rotifers, and unicellular algae. Ingestion of all food items was detected but the larvae died at day 5. Whether the larvae died from high water temperature (29.4°C) or were unable to digest ingested food will have to be explored in future research.

Both the red snapper and vermilion snapper appear to offer excellent mariculture potential. Proper larvae care is a most crucial area which must be addressed before the full potential of either can be determined.

Other species

The species mentioned to this point can be marketed easily along the northern Gulf of Mexico and demand a fairly high market price. Other species whose potential as a mariculture crop may offer promise in the future include spotted seatrout, red drum, croaker, several species and strains of tilapia, mullet, and oysters.

Spotted seatrout and red drum raised in mariculture environments may represent the only legal method of marketing these species in the future if current trends imposing serious restraints on commercial fishermen continue. Monitoring and assessment programs for marine fishery stocks in both Alabama and Mississippi have shown downward trends in the relative abundance of croaker in the estuaries of the two states. This downward trend is occurring at a time when demand for the species for human consumption is increasing. Mono-sex culture of some of the more temperate and saline tolerate tilapia may offer potential to mariculturists in the future. In most areas of the United States along the Gulf of Mexico it will be necessary to overwinter brood stock, but rapid growth of juveniles and good production may offset the added expense of overwintering in artificially heated water. Mullet and oysters could offer a very inexpensive mariculture product because of their ability to live and grow on strained, or sieved, plankton. This attribute certainly qualifies the two animals for polyculture with another primary species.

CONCLUSIONS

The potential for mariculture in coastal Alabama is good. Technology for a few species has advanced to a point where dependable crops of marketable products can be grown, but other species with good potential have not yet crossed the "dependable" barrier. Unfortunately, we are living in a time when budgetary restraints are bringing about cutbacks in virtually all Federal, State, and local agencies and the prospect of continued mariculture research on a national level is not promising.

It has never been the object of mariculture research at CPMC to demonstrate the ability to replace existing fisheries, but rather to demonstrate that efficiency can be achieved through the control of certain environmental parameters, thereby demonstrating viable alternatives for specific valuable or unique fisheries. Even in the face of budgetary restraints, we still feel that this is an important approach to fiscal problems now facing the international fishing industry. With a growing human population and reduction of natural habitat, the importance of mariculture is greater now than ever.

It is quite possible that the utilization of dredged material sites for mariculture projects can offset two of the major deterrents to this developing industry: (a) the cost of waterfront or near waterfront land, and (b) the flooding liability of waterfront or near waterfront land.

The cost of waterfront property, particularly if the property has a potential for either residential, industrial, or agricultural uses, can certainly discourage capitalization by a mariculture venture whose potential value is uncertain. Containment sites, because of residual salts, will have only limited potential for agriculture and low desirability for residential sites, leaving industrial use as the principal competition. It is quite likely that the price per unit area of spoil containment sites will be far more attractive to the mariculturist than other areas where land use may be more competitive.

Of major concern to mariculture operations is the possibility of losing a crop, or more importantly, losing a production facility to storm tides or turbulent water brought about by high winds. An asset of dredged material sites is apparent by the gained elevation. This asset may suffice to turn an unusable area into a most feasible area.

LITERATURE CITED

Donaldson, L. R. 1978. "People are Important," World Mariculture Soc., Vol 9, pp 13-17.

Gulf of Mexico Fishery Management Council. 1979. "Environmental Impact Statement and Fishery Management Plan for Reef Fish Resources of the Gulf of Mexico," Tampa, Fla., 164 p.

Korringa, P. 1975. "From Fishing to Farming the Sea," Keynote Address. Proc. World Mariculture Soc., Vol 6, pp 17-29.

Minton, R. V., Hawke, J. P., and Tatum W. M. In Press. "Hormone Induced Spawning of Red Snapper," Aquaculture.

Tatum, W. M. 1973. "Brackish Water Cage Culture of Rainbow Trout (*Salmo gairdneri*) in South Alabama," Trans. Am. Fish. Soc., Vol 102, pp 826-828.

__________. 1976a. "Comparative Growth and Mortality of Winter Cultured Rainbow Trout (*Salmo gairdneri*) in Freshwater and Brackish Water Ponds in South Alabama," Proc. World Mariculture Soc., Vol 7, pp 71-78.

__________. 1976b. "Experimental Pond Production of Selected Marine Species," Alabama Dept. of Cons. and Nat. Res., Mar. Resour. Div., Fed. Aid Annual Progress Report, Project 2-263-R-1: 22 pp (Mimeo File Report).

Tatum, W. M., and Trimble, W. C. 1977. "Experimental Pond Production of Selected Marine Species," Alabama Dept. Cons. and Nat. Resour., Mar. Resour. Div., Fed. Aid Annual Progress Report. Project 2-263-R-2:24 pp (Mimeo File Report).

__________. 1978. "Monoculture and Polyculture Pond Studies with Pompano (*Trachinotus carolinus*) and Penaeid Shrimp (*P. aztecus, P. duorarum* and *P. setiferus*) in Alabama, 1975-1977," Proc. World Mariculture Soc., Vol 9, pp 433-446.

Tatum, W. M., Hawke, J. P., Minton, R. V., and Trimble, W. C. 1982. "Production of Bull Minnows (*Fundulus grandis*) for the Live Bait Market for Coastal Alabama," Alabama Marine Resources Bulletin, Vol 13, pp 1-35.

Trimble, W. C. 1980. "Production Trials for Monoculture and Polyculture of White Shrimp (*P. vannamei*) or Blue Shrimp (*P. stylirostris*) with Florida Pompano (*Trachinotus carolinus*) in Alabama, 1978-1979," Proc. World Mariculture Soc., Vol 11, pp 44-59.

Tiews, K. 1977. "International Organizations and Aquaculture Development," Keynote Address, Proc. World Mariculture Soc., Vol 8, pp 35-46.

ECONOMICS OF PRODUCING AND MARKETING FARM-RAISED CATFISH

by
James G. Dillard and John E. Waldrop
Mississippi State University
Mississippi State, Mississippi 39762

James G. Dillard

ABSTRACT

This paper presents economic data concerning production and marketing of farm-raised catfish in the Delta of Mississippi. No attempt is made to assess the economics of producing catfish in dredged material containment sites; however, any new production from containment sites must compete in the long run with the rapidly expanding production and marketing systems described. Costs of production of farm-raised catfish, f.o.b. processing plant, were calculated to range between 58.7 and 66.4 cents per pound for farm sizes ranging between 163 and 643 water surface acres, respectively. Most of the processing capacity for farm-raised catfish is located in Mississippi. The processed product moves through three major market channels. Retail grocery outlets, food service distributors, and catfish speciality restaurants each handle about one third of catfish sales. Sales of farm-raised catfish are growing rapidly, and prospects for continuing growth are good.

INTRODUCITON

This paper will not attempt to assess the feasibility of producing and marketing catfish from dredged material containment sites, but rather will present a summary of research conducted at Mississippi State University concerning the economics of producing and marketing farm-raised catfish. While there is no known production in containment sites, any future use of these sites for catfish production must compete with the production and marketing system reported in this paper.

The program description for this workshop stressed "data gaps" and "research needs" as a major question. As you will conclude from this

report, there are many wide knowledge gaps and a serious shortage of data even though the catfish industry is the most highly developed and largest aquacultural industry in the United States.

BACKGROUND

In order to obtain an understanding of how, when, and why the commercial catfish industry developed in the United States, interviews were conducted with the "known" pioneers of the industry in the states of Mississippi, Alabama, and Arkansas. The following is a summarization of these interviews.

The first commercial sale of catfish occurred in 1960 in Arkansas. The brood fish were obtained from the Mississippi River. The fish were raised in ponds that were originally built for producing buffalo fish for stocking in rice fields. Buffalo fish production in rice fields failed to attain commercial status and catfish were stocked as an alternative use of the facilities. With technical assistance from the University of Auburn and the Arkansas Game and Fish Commission, catfish production began a modest growth in Arkansas. At about the same time, an owner of a grocery store in Alabama began to process and sell in his store catfish he had previously stocked in a small pond (less than 5 acres). Based on this market experience, both the commercial production and the processing began in the state of Alabama. Alabama is now second in catfish production with major processing facilities.

Soon after these modest beginnings in Arkansas and Alabama, individuals in Mississippi became interested in catfish production as an alternative crop to the more traditional row crops in the Delta area. Fish produced in Mississippi, for the most part, were transported to Arkansas and/or Alabama for processing.

As production increased in the three states, processing and marketing became more and more an acute problem. Several small processing plants had been developed, many of which subsequently failed for various reasons. In 1969, a commercial production unit and a commercial processing plant began operating in Mississippi that has continued to be successful. Producers, however, did not claim industry status until 1974. Prior to 1974, fish were stocked in the early spring, fed through the summer, and harvested in the fall of the year. Following the fall harvest, fish were not available until the following fall. Such periodic production was a major handicap in developing markets. In 1974 production and processing were such that fresh and/or frozen fish in limited quantities could be supplied throughout the year. The ability to supply markets through the year improved the market potential substantially and farm-raised catfish for the first time was labeled as an industry.

The industry has grown substantially and is continuing to expand in all aspects at a rapid rate. There are now some 60,000 acres of ponds devoted to commercial catfish production. At least 100 million pounds (live weight) of catfish will be harvested and sold in 1982, 40 million pounds more than in 1981.

The rapid growth of the industry during the decade 1971-1981 can be largely explained by its relative profitability. Throughout this period, average prices paid to producers exceeded estimated cost of production in the Mississippi Delta area (Figure 1). Surface acres of water used for food fish production increased from less than 15,000 acres in 1975 to over 50,000 acres in 1981. By the beginning of 1982, estimated total cost of production exceeded average prices paid to producers by processors.

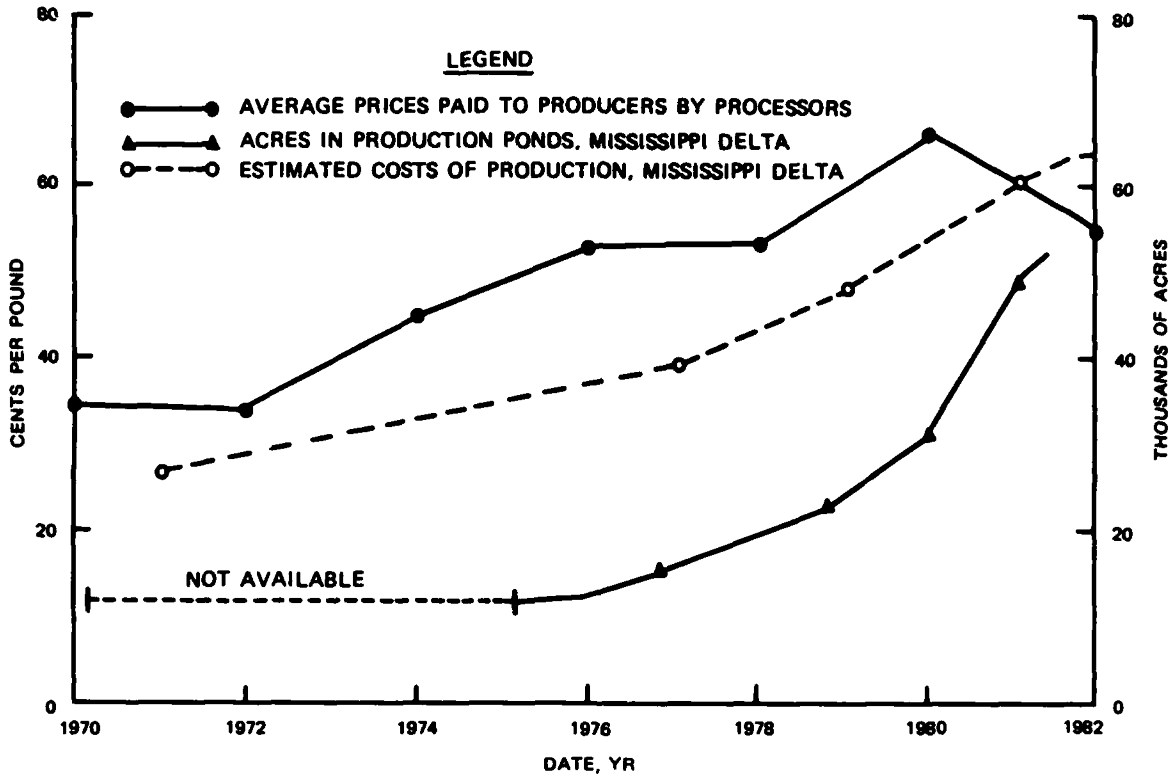


Figure 1. Average prices paid to producers (Burk and Waldrop 1978; Foster and Waldrop 1972; Giachelli et al. 1981; Waldrop and Smith 1980; Welbonn N.D.; U. S. Department of Agriculture 1982)

Cost of production estimates were updated and published in much detail in June 1982 (Giachelli et al. 1982). A summary of those cost data will be presented here. Some of the more important assumptions underlying these costs are: (1) stocking rate of 4,500 fingerlings per acre; (2) 5 percent mortality; (3) average harvesting weight of 1.25 pounds; (4) 5344 pounds of fish produced per water acre, and (5) pond size of 20 land acres.

Costs were calculated for three sizes of farms: 163, 323, and 643 acres. In each case, it was assumed that 3 acres was needed for buildings, access roads, etc. Estimated 1982 investment requirements are presented below:

Item	Farm Size 163 acres	323 acres	643 acres
Land	$244,500	$484,500	$964,500
Pond construction	122,865	233,005	456,911
Water supply	35,000	70,000	140,000
Feeder & storage	16,750	22,650	34,300
Disease, weed equip.	10,363	17,742	32,914
Misc. equip.	131,968	182,868	298,328
Total investment	561,446	1,010,765	1,926,953

Total investment ranged from $561,446 for the 163-acre farm to $1,926,953 for the 643-acre farm. With the most efficient size (643 acres), investment amounts to $3,010 per acre. It is obvious that investment requirements for farm-raised catfish production are quite high.

The investment requirements were "annualized" to determine annual ownership costs. These costs are presented below:

Item	Farm Size 163 Acres	323 Acres	643 Acres
Depreciation	$31,208	$53,576	$98,051
Interest	53,778	98,954	190,380
Taxes & insurance	2,887	3,795	5,966
Total ownership	87,873	156,325	294,397

Annual operating costs are presented below. By far the highest cost item in operating costs is feed, which accounts for more than half (51-57 percent) of the total operating costs.

Item	Farm Size 163 Acres	323 Acres	643 Acres
Repairs & maintenance	$11,401	$17,826	$30,120
Fuel	21,701	42,901	87,011
Chemicals	4,210	8,338	16,474
Fingerlings	45,299	91,520	183,448
Feed	200,040	404,151	810,105
Labor	53,489	61,399	85,580
Harvest & haul	28,689	57,962	116,184
Liability insurance	1,740	2,349	3,330
Interest	21,620	40,101	77,439
Total operating	388,189	726,547	1,409,691

Annual total costs (ownership cost + operating cost) per pound are summarized below for the three farm sizes. Total costs ranged from 66.4 cents per pound for the 163-acre farm to 58.7 cents per pound for the 643-acre farm. For the 643-acre farm, annual ownership costs (10.2 cents per lb) represents approximately 17 percent of total costs (58.7 cents per lb).

Item	Farm Size 163 Acres	323 Acres	643 Acres
Ownership	12.3¢	10.8¢	10.2¢
Operating	54.1	50.1	48.5
Total	66.4	60.9	58.7

CATFISH MARKETING

There has been relatively little research aimed at seafood marketing problems in general, and even less research devoted to aquacultural and maricultural products. This is no doubt because aquaculture and mariculture are new technologies that have emerged during the last few years, and, consequently, these products have been relatively unimportant in the U. S. marketplace. In 1980, fish, including shellfish and game fish, made up only 7 percent of all meat products consumed in the United States (USDA 1981).

There is some evidence that consumption patterns are changing and that fish are becoming a more important item in the consumer's budget. Figure 2 shows index of per capita consumption of meat and fish for the period 1967-1978. Since 1971, per capita consumption of red meat has trended downward, while consumption of fish has generally trended upward since 1967.

Figure 2. Index of per capita consumption (USDA 1981)

Some of the upward trend has no doubt been due to the introduction of farm-raised catfish. Figure 3 shows the growth in round-weight processed catfish from 1970-1981, with projections through 1982. Farm-raised catfish

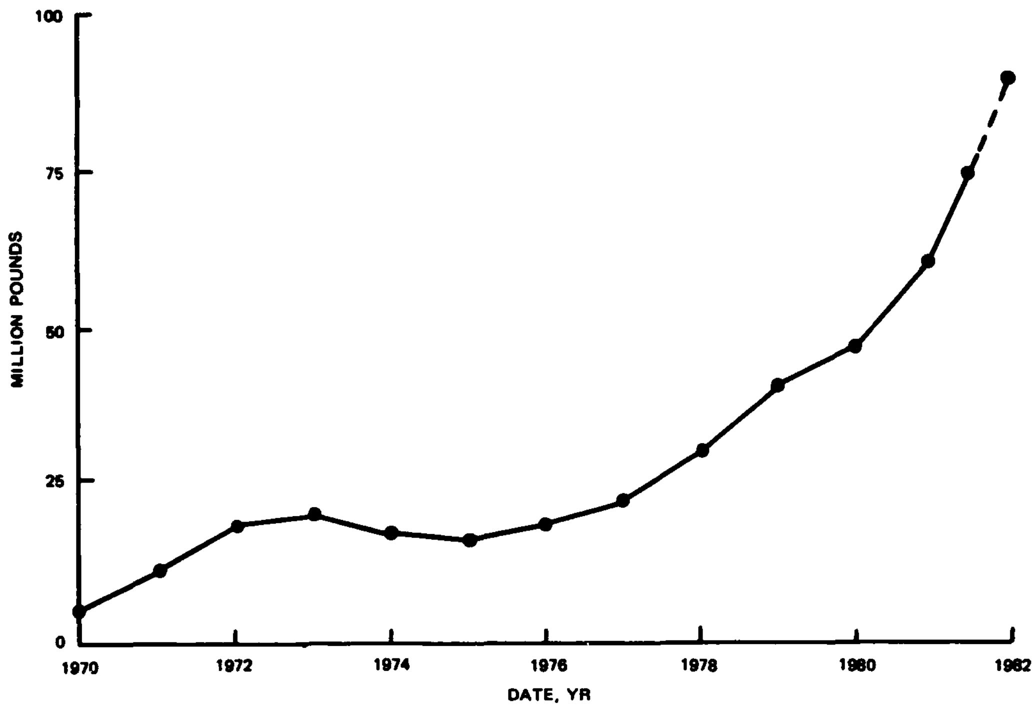


Figure 3. Round weight processed (USDA 1982)

sold by processors by month is shown in Figure 4. The dotted line represents average monthly sales, and has been increasing at an increasing rate. Sales during the first six months of 1982 were 56 percent higher than during the same period a year earlier. While the monthly variation in sales by processors remains somewhat erratic, the problem faced by the industry in its early days of unavailability of catfish during some months has largely disappeared.

Most of the processing capacity is located in the Mississippi Delta. The capacity has remained fairly constant during the past three years at approximately 100 million pounds round weight, but is once again experiencing growth. Plants currently under construction will add an additional 80-90 million pounds, one shift capacity. Once the plants currently under construction are operational, processing capacity will su ntially exceed current farm production. This will no doubt lead to eve competition among processors, both for fish and markets. If the i ed competition leads to additional promotions and advertisement of the prou ct, demand for catfish will likely continue to expand. Per capita consumption of farm-raised catfish is still below 0.5 lb annually, so there is ample room for expansion.

A survey was conducted in 1979 to determine structural and operational characteristics and procurement and marketing practices of commercial catfish processors (Miller et al. 1981). It was learned that five of the nine firms in the survey handled 98 percent of total pounds processed. Thus, the industry is characterized by a high degree of market concentration. All of the larger firms were located near their source of supply, since fish are

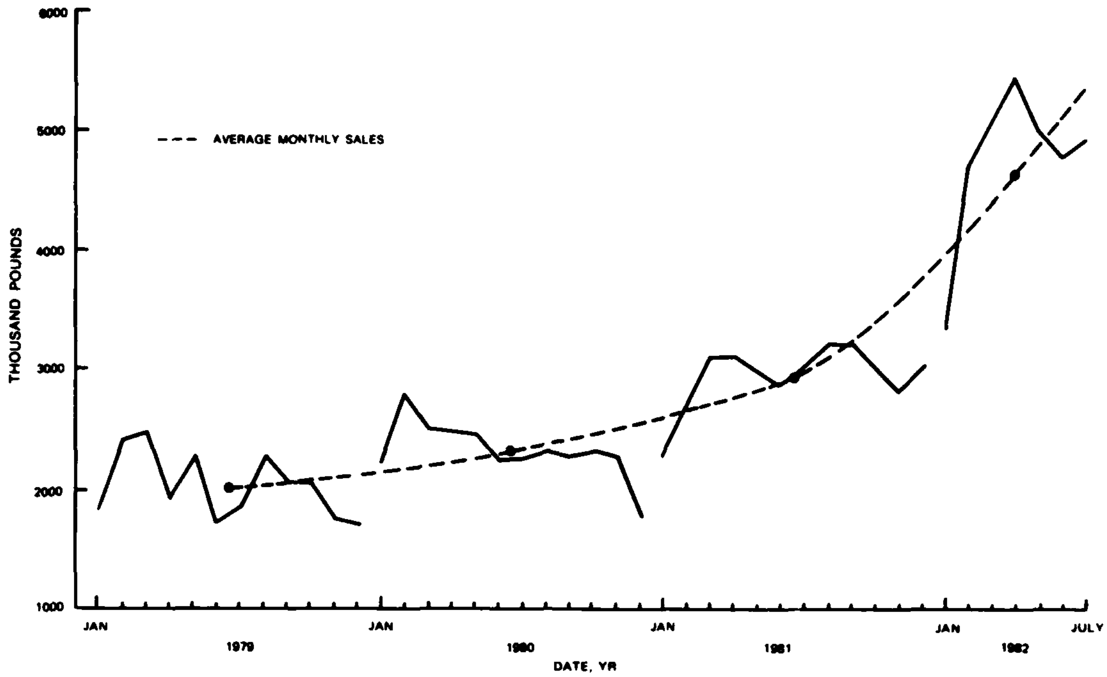


Figure 4. Catfish sold by processors 1979 - July 1982 (USDA 1982)

delivered live to the processing plants. Four of the five major firms were located in the Delta of Mississippi.

The total one-shift capacity of the firms contacted was 332 thousand pounds per day, or approximately 85 million pounds annually.

In 1979, 72 percent of catfish processed by the firms interviewed came from individual producers, the remainder came from processor-controlled production. Seventy-six percent of the fish processed were in the 0.75- to 2.0-lb range.

The study revealed three major distribution channels, each handling about 33 percent of total sales. These were retail grocery outlets, food service distributors, and catfish specialty restaurants. Figure 5 shows the amount of fresh and frozen fish going through each channel.

Sixty percent of all sales in 1979 were handled by food brokers. Processing firms used trade magazines, brochures, table tents for restaurants, recipes, and other point of purchase materials as their major advertising methods. Some cost-sharing was also used with customers for newspaper ads.

Following the survey of processors, a survey was conducted in 1980 of the market channels identified in the processor survey (Dixon et al. 1982). The market channels survey was limited to the principal market area for catfish. Figure 6 shows the market area, consisting of the southeastern and parts of the southwestern and midwestern United States. This is more or less the traditional catfish-consuming area of the country.

Most of the firms interviewed handled farm-raised catfish for at least

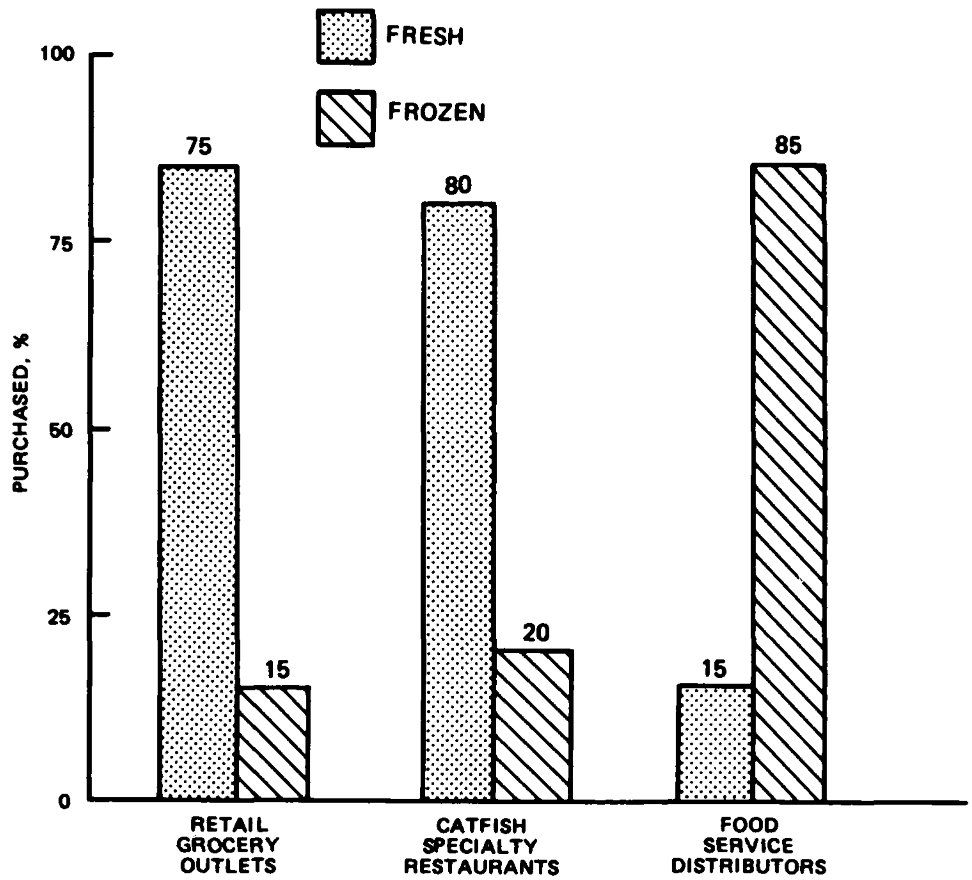


Figure 5. Percent of fresh and frozen catfish purchased by market outlet, 1979 (Miller et al. 1981)

3 years. In all outlets, except fish distributors and catfish restaurants, farm-raised catfish made up a small percentage of total sales.

Chain grocery distributors, fish distributors, and poultry distributors handled mostly fresh fish, while food service distributors, food brokers, and catfish specialty restaurants handled mostly frozen fish. Most farm-raised catfish were distributed as whole fish in 1979. Since that time, the fillet market has expanded greatly.

Most firms interviewed agreed that sales of farm-raised catfish were highest in the spring months, and many of the firms reported problems with obtaining adequate supplies during these months.

All firms interviewed were satisfied with the way in which farm-raised catfish were packaged for distribution. Chain grocery distributors, food service distributors, and food brokers expressed interest in a portion-controlled, prebreaded product.

Very few quality-related problems were reported. A low percentage of firms interviewed reported infrequent problems in the past with "off-flavor."

The survey revealed that only 24 percent of both chain grocery stores and food services distributors in the geographic area studied handled

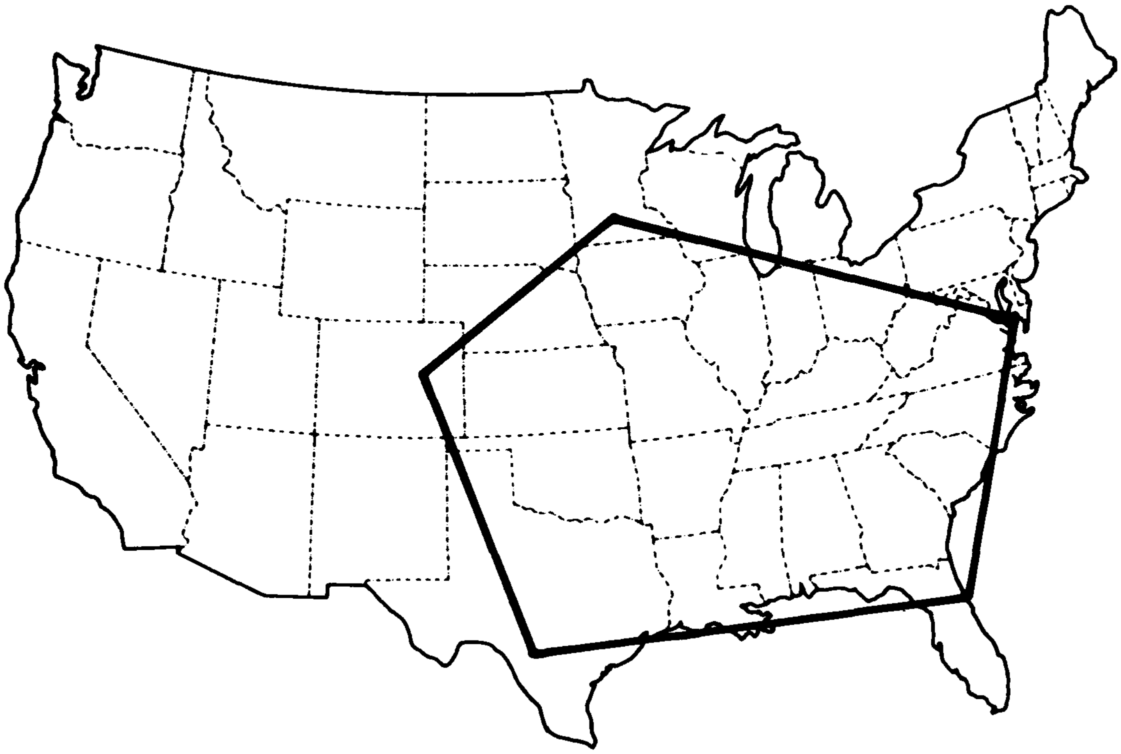


Figure 6. Approximate geographic market area for processed farm-raised catfish (Miller, Conner, and Waldrop 1981)

farm-raised catfish. The high percentage of chain grocery stores and food service distributors who do not handle the product suggests a potential for further expansion of the market.

All firms interviewed expressed a need for more industry-wide promotion of farm-raised catfish.

CONCLUSIONS

The growth in consumption of farm-raised catfish will likely continue. With current emphasis on good nutrition and health, farm-raised catfish should find a place in the diets of more and more people. The product is high in protein, low in cholesterol, and available year-round. Fresh farm-raised catfish has a shelf life of 12-14 days, and is extremely stable when frozen. In fact, there is evidence to suggest that the freshest and best form is frozen, and the trend in sales suggests that the frozen form is gaining in acceptance (Figure 7). The product is odorless both in handling and cooking. It can be purchased whole, steaked, or filleted (without bones). The product is attractive and can be prepared in many ways.

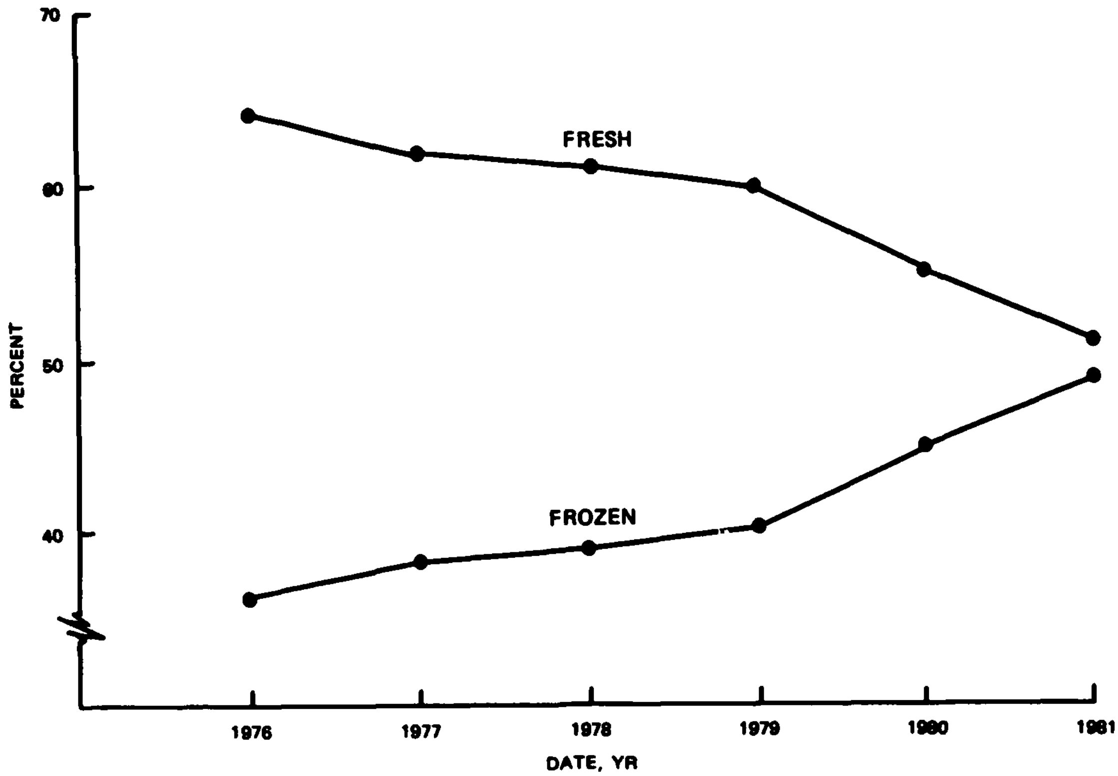


Figure 7. Catfish sold by processors (USDA 1982)

As stated earlier, no attempt is made here to assess the feasibility of producing catfish in dredged material containment sites. However, anyone considering use of these sites for catfish production will have to compete with the production and marketing system described. Potential producers in dredged material containment sites may want to study in more detail the publications cited in this paper, although there is no intent to imply that results of these studies will necessarily apply directly to other production systems.

REFERENCES

Burke, R. L., and Waldrop, J. E. 1978 (Jul). "An Economic Analysis of Producing Pond-Raised Catfish for Food in Mississippi," Mississippi Agricultural and Forestry Experiment Station Bulletin 870, Mississippi State University.

Dixon, D. A., Jr., Miller, J. S., Conner, J. R., and Waldrop, J. E. 1982 (Mar). "Survey of Market Channels for Farm-Raised Catfish," Agricultural Economics Research Report No. 132, Mississippi Agricultural and Forestry Experiment Station, Mississippi State University.

Foster, H., and Waldrop, J. E. 1972 (Jan). "Cost Size Relationships in the Production of Pond-Raised Catfish for Food," Mississippi Agricultural and Forestry Experiment Station Bulletin 792, Mississippi State University.

Giachelli, J. W., Coats, R. E., and Waldrop, J. E. 1982 (Jun). "Mississippi Farm-raised Catfish--January 1982 Cost of Production Estimates," Agricultural Economics Research Report No. 134, Mississippi Agricultural and Forestry Experiment Station, Mississippi State University.

Miller, J. S., Conner, J. R., and Waldrop, J. E. 1981 (Oct). "Survey of Commercial Catfish Processors--Structural and Operational Characteristics and Procurement and Marketing Practices," Agricultural Economics Research Report No. 132, Mississippi Agricultural and Forestry Experiment Station, Mississippi State University.

Waldrop, J. E., and Smith, R. D. 1980 (Jul). "An Economic Analysis of Producing Pond-Raised Catfish for Food in Mississippi, A January 1980 Update," Agricultural Economic Research Report No. 103, Mississippi Agricultural and Forestry Experiment Station, Mississippi State University.

Wellborn, T. L. Not Dated, "Status of Fish Farming in Mississippi," Mimeographed Reports, Wildlife and Fisheries Department, Mississippi Cooperative Extension Service, Mississippi State University.

U. S. Department of Agriculture. 1981. Agricultural Statistics, Table 764, Washington, D. C.

U. S. Department of Agriculture. 1982 (Apr). Aquaculture Outlook and Situation, Economic Research Service, Washington, D. C.

POND MANAGEMENT: POLYCULTURE VS. MONOCULTURE

AD P002136

by
R. Kirk Strawn
Department of Wildlife & Fisheries Sciences
Texas A&M University
College Station, Texas 77843

ABSTRACT

Polyculture, extensively used in Israel and the Far East, makes better use of resources than monoculture, thus increasing yield and returns. Some species combinations shown to be productive on the Gulf Coast are blue shrimp (*Penaeus stylirostris*) and green shrimp (*P. vannamei*), striped mullet (*Mugil cephalus*) and various shrimp (*Penaeus* spp.), and striped mullet (*M. cephalus*) cultured with black drum (*Pogonias cromis*). Redfish (*Sciaenops oscellatus*) and blue tilapia (*Talipia aurea*) need to be evaluated both together and in polyculture with other species in dredged material disposal areas.

Polyculture of the right species combinations increases total production in a culture system while using about the same capital investment as required for monoculture and requires less variable costs to produce similar poundage of product than in monoculture. One species, preferably the least valuable, may do less well in polyculture than in monoculture, but polyculture is a success if total production is greater than if the component species were in monoculture. Even a species of no market value would be desirable in polyculture if its inclusion sufficiently increased the production of a high-priced species.

A combination of species with diverse food habits is needed to make fullest possible use of natural and supplemental foods. The presence of one species may stimulate the feeding activity of another (Gibbard et al. 1979, Rossberg and Strawn 1980a). One species may make natural food more available to another, like birds following a farmer's plow. A species may control an undesirable species that would depress growth or be detrimental to it and other species in polyculture. Included here would be species that eat predaceous insects, eat vegetation, and feed on phytoplankton. Ones such as the silver carp (*Hypophthalmichthys molitrix*) that control algae blooms are needed in fertilized ponds and ponds heavily fertilized by supplemental feeding. An overpopulation of algae both uses an excessive amount of oxygen at night and is subject to mass mortality followed by their decay depleting the dissolved oxygen. I find a few goldfish (*Carassius auratus*) and blue tilapia (*Tilapia aurea*) beneficial for control of filamentous algae and

duckweed in guppy (*Poecilia reticulata*) ponds in my yard. In cage culture, a species that controls fouling on the meshes is useful.

Some unlikely combinations can be used such as predator and prey species provided the prey species is given a head start and the predator is stocked at a small size (Tatum and Trimble 1978, Rossberg and Strawn 1980b, and Huner et al. 1980).

Disadvantages of polyculture over monoculture are that it takes extra labor to separate the species at harvest and all species may not be ready for harvest at the same time. In Israel, striped mullet are raised a second growth season and great care has to be used not to kill them during the harvest of the other species which require only one growing season. Obtaining the various species at the right size and time for stocking requires careful planning and good luck.

It is easier to find one profitable species than two or more. There are few species that can be raised and sold for profit in competition with harvest from the wild. In Texas, crawfish (*Procambarus acutus* and *P. clarki*), gulf killifish (*Fundulus grandis*), and channel catfish (*Ictalurus punctatus*) can be raised and sold for a profit. Additional species are raised for sale to stock private impoundments. The red drum (*Sciaenops oscellata*) and blue tilapia are good food fish and show promise for culture in favorable environments.

Penaeid shrimp have great potential but the best species for culture are from the Indo-Pacific Ocean (Trimble 1980). The supply of their postlarvae for stocking in Texas is not reliable. Brood stock is currently imported at a great cost per viable spawner. Facilities are needed for overwintering of pond-raised brood stock.

Escapement and establishment of populations of these exotic shrimp on the Atlantic side of the Americas would permit sourcing of wild females. However, the effect of exotic shrimp on local species can only be guessed, and care needs to be taken to prevent their escape from shrimp farms. Danger of their escape would limit the use of low-lying spoil areas subject to flooding during storms.

Polyculture has been most used in Israel and the Far East. In Israel, common carp (*Cyprinus carpio*), silver carp, tilapia, and striped mullet (*Mugil cephalus*) have commonly been cultured together. Even with this combination, there is uneaten algae which milkfish (*Chanos chanos*) would utilize if they were available for stocking. In recent years, grass carp (*Ctenopharyngodon idellus*) have been added and are fed grass that is raised and cut for cattle feed. Bighead carp (*Aristichthys nobilis*) are replacing silver carp because silver carp are bad jumpers and are dangerous to seine. Striped mullet bring the best price of the cultured species and are considered a quality food fish in the Middle East.

The Israeli system of polyculture has its stresses. The younger generation doesn't like to eat carp as much as their parents from Europe and demand for carp is down (Sarig 1982). When William H. Neill, Robert R. Stickney, and I were in Israel in May 1981, I had hoped that Dr. Stickney would photograph one of the beautiful tile-lined live-carp tanks built next to the meat market in a supermarket, but they had been removed. Silver carp were never popular and it is thought that a similar coloration to grouper may help sell bighead carp. Wild fry of the striped mullet are collected October-December

for stocking. The supply is short and catching them is labor-intensive. After December, young of *Mugil capito*, which doesn't grow as fast, are present in the collecting areas.

In recent years Dr. David Aldrich's and my students have performed polyculture experiments in 0.1-ha ponds at the Cedar Bayou Generating Station of the Houston Lighting & Power Company. Jane Ojeda cultured various ages of blue shrimp (*Penaeus stylirostris*) together to test staggered stocking (a form of polyculture) and the situation in natural populations. Indications were that crop value would be increased this way (Ojeda et al. 1980). She polycultured, per square meter, 2.1 blue and 1.5 white shrimp (*P. setiferus*) in the ponds in 1978 (Strawn et al. 1979). Polyculture yielded more kilograms of shrimp per pond than did monoculture of 4.0 white shrimp per square meter. During the winter of 1978-1979 she overwintered 1,000 of each species in a pond. Only white shrimp survived the combination of low temperatures (down to 7.0°C) and conductivities as low as 2.0 mmhos/cm (Strawn et al. 1980). These white shrimp were postlarvae in late July 1978 and the survivors were 23.6 heads on count per kilogram in early July 1979, averaging 42.5 g each.

Chamberlain et al. (1981), raising shrimp at Corpus Christi, Texas, found that the polyculture of a small percentage of blue shrimp with green shrimp (*P. vannamei*) resulted in faster growth for both species than when they were monocultured. Jane Ojeda polycultured white shrimp with striped mullet in two ponds and white shrimp only in two additional ponds. Postlarvae white shrimp were stocked at $4.1/m^2$. Before the shrimp averaged 5 g, mullet weighing about 6 g were stocked at $0.135/m^2$. Shrimp yields were similar in polyculture and monoculture, except for a partial kill caused by low oxygen concentration in one of the polyculture ponds. The mullet production was a bonus.

Tatum and Trimble (1978) at the Claude Peteet Mariculture Center in Alabama found that Florida pompano (*Trachinotus carolinus*) could be cultured with either native brown or white shrimp. Trimble (1980) cultured Florida pompano with both blue shrimp and green shrimp and reported greater economic returns derived from the polyculture of shrimp with pompano than from monoculture of either. Karen Rossberg cultured brown shrimp (*P. aztecus*) with Florida pompano, black drum (*Pogonias cromis*), and striped mullet at Cedar Bayou (Rossberg and Strawn 1980a). These pond-raised shrimp were stocked $0.3/m^2$ the first of July at 111.1 heads on count per kilogram and averaged 31.5 to 37.6 count by pond when harvested the last of October and first of November. They were the largest produced in several years of research at Cedar Bayou. This indicates that polyculture with fish may be the means to produce large pond-reared brown shrimp. Even moderate stocking rates result in monocultured brown shrimp reaching a growth plateau very quickly. Quick and Morris (1976) reported on brown shrimp grown at Freeport, Texas, in 0.1-ha ponds containing dredged material from the Gulf Intracoastal Waterway channel in Galveston Bay, Texas. Stocking rate was 9.9 postlarvae/m^2 and little growth occurred after 40 days. At the end of 3 months, they averaged by pond 238 to 401 heads on count per kilogram. These shrimp would have grown somewhat larger if they had been fed.

Mr. Hann-Jin Huang at Cedar Bayou recently harvested 211 kg of 52.4 count per kilogram of heads on green shrimp plus 83.5 count blue shrimp from a 0.1-ha pond in which they were polycultured with 26 striped mullet. These

mullet were less than a year old and weighed 0.3 to 0.9 kg each at harvest.

Some combinations are to be avoided. Peter Perschbacher, who is currently conducting research at Cedar Bayou, found sheepshead minnows (*Cyprinodon variegatus*) to be detrimental to the production of gulf killifish. There is little market for sheepshead minnows.

A need exists for ways to develop a market for high quality, pond-raised organisms already proven in polyculture and trials of various combinations of species having present economic values in the local market. Of the several fish combinations tested by our graduate students at Cedar Bayou, the best combination was black drum and striped mullet. Both grew faster when polycultured together than when monocultured. Production of black drum stocked $0.5/m^2$ with striped mullet at $0.05/m^2$ was 40% greater than for 0.5 black drum per m^2 in monoculture (Rossberg and Strawn 1980b). Eating quality of both was excellent and much superior to Atlantic croaker (*Micropogonias undulatus*) raised under similar conditions. We have had neither off-flavor problems with striped mullet nor parasites in the flesh of black drum. These undesirable occurrences have made the market value of both species low in Texas.

Redfish and blue tilapia need to be evaluated in polyculture and with other candidates for culture on dredged material disposal areas. To grow tilapia to a marketable size before cold weather could kill them, fingerlings from the previous breeding season could be overwintered in either spring areas or in heated effluent at a power plant.

Areas for further research are species combinations and percentages; stocking rates, sizes and times; feeding rates, frequencies, and the effects of times of day the fish are fed; and the contributions of various species to water quality and total production. Jones and Strawn (in press) found that morning feedings favored black drum in cage polyculture and afternoon feedings favored Atlantic croaker. Blue crabs (*Callinectes sapidus*) usually find their way into the ponds at Cedar Bayou. Perhaps pond cleaning by these scavengers stocked in proper numbers might do more good for water quality than they do harm as predators. Experiments testing their effect on production would be interesting. If the addition of a few blue crabs proved beneficial, their sale at harvest would increase economic returns.

LITERATURE CITED

Chamberlain, G. W., D. L. Hutchins and A. L. Lawrence. 1981. Monoculture and polyculture of *Penaeus vannamei* and *P. stylirostris* in ponds. Proceedings World Mariculture Society 12(1)251-270.

Gibbard, G. L., K. Strawn and D. V. Aldrich. 1979. Feeding and aggressive behavior of Atlantic croaker, black drum, and striped mullet in monoculture and polyculture. Proceedings World Mariculture Society 10:241-248.

Huner, J. V., W. G. Perry, Jr., R. A. Bean, M. Miltner and J. W. Avault, Jr. 1980. Polyculture of prawns, *Macrobrachium rosenbergii*, and channel catfish fingerlings, *Ictalurus punctatus*, in Louisiana. Proceedings of the Louisiana Academy of Sciences 43:95-103.

Jones, F. V., and K. Strawn. 1982. Aspects on the growth and feeding behavior of cage-polyculture marine fish in a heated water system. Journal of World Mariculture Society 13(2)(in press).

Ojeda, J. W., D. V. Aldrich and K. Strawn. 1980. Staggered stocking of *Penaeus stylirostris* in brackish-water ponds receiving power plant cooling water. Proceedings World Mariculture Society 11:23-29.

Quick, J. A., Jr., and J. A. Morris. 1976. Experimental extensive culture of Penaeid shrimp in a simulated dredged material disposal area. Proceedings World Mariculture Society 7:305-325.

Rossberg, K. S., and R. K. Strawn. 1980a. Comparative growth and survival of brown shrimp cultured with Florida pompano, black drum, and striped mullet. Proceedings World Mariculture Society 11:219-225.

__________. 1980b. Induced feeding and growth enhancement of black drum when cultured with Florida pompano and with striped mullet. Proceedings World Mariculture Society 11:226-234.

Sarig, S. 1982. Fisheries and fish culture in Israel in 1980. Bamidgeh 34:3-19.

Strawn, K., D. V. Aldrich, W. B. Wilson, L. M. Wiesepape, F. V. Jones, G. M. Ojeda, B. A. Carr, K. S. Rossberg, J. W. Ojeda, D. R. Johnson, B. H. Pridgeon and J. M. Smith. 1979. The effects on selected organisms of water passing through the Cedar Bayou Generating Station. Annual Progress Report for 1978. Texas Agricultural Experiment Station Project 1869, College Station, Texas.

Strawn, K., D. V. Aldrich, W. B. Wilson, L. M. Wiesepape, G. M. Ojeda, B. A. Carr, P. B. Waas, J. M. Ojeda, B. A. Pridgeon, J. M. Smith and R. C. Biever. 1980. The effects on selected organisms of water passing through the Cedar Bayou Generating Station. Annual Progress Report for 1979. Texas Agricultural Experiment Station Project 1869, College Station, Texas.

Tatum, W. M., and W. C. Trimble. 1978. Monoculture and polyculture pond studies with pompano (*Trachinotus carolinus*) and penaeid shrimp (*Penaeus aztecus*, *P. duorarum*, and *P. setiferus*) in Alabama, 1975-1977. Proceedings World Mariculture Society 9:433-446.

Trimble, W. C. 1980. Production trials for monoculture and polyculture of white shrimp (*Penaeus vannamei*) or blue shrimp (*P. stylirostris*) with Florida pompano (*Trachinotus carolinus*) in Alabama, 1978-1979. Proceedings World Mariculture Society 11:44-59.

AD P002137

POND MANAGEMENT: WATER QUALITY CRITERIA AND CONTROL

by
William D. Hollerman
Department of Fisheries and Allied Aquacultures
Agricultural Experiment Station
Auburn University, Alabama 36849

ABSTRACT

Proper management of water quality variables in aquaculture operations, including those in dredged material containment areas, is imperative if success is expected. Dissolved oxygen, perhaps the most critical factor in fish culture systems, can be managed with mechanical aeration. Carbon dioxide may be harmful to fish when oxygen concentrations are low. Hydrated lime is effective in removing carbon dioxide from water. An imbalance between calcium hardness values and alkalinity concentrations may cause high pH levels lethal to fish. Ammonia and nitrite often accumulate in aquaculture systems. A pond treatment of sodium chloride protects fish from nitrite toxicity. Filter alum may be used to remove colloidal clay particles from water, eliminating turbidity that may limit photosynthesis.

The term "water quality" includes all the chemical, physical, and biological factors that influence the intended use of a body of water. However, only a few of the many water quality variables in a pond will normally play an important role in aquaculture. This paper will discuss selected water quality variables and management techniques that may be of particular concern to aquaculture operations in dredged material containment areas. A complete discussion of water quality in fish culture ponds may be found in Boyd (1979a, 1982).

DISSOLVED OXYGEN

Dissolved oxygen is often considered the most critical factor in fish culture systems (Boyd 1982). Though a major component of air, oxygen is not greatly soluble in water. Solubility decreases with increasing temperature, increasing altitude (decreasing atmospheric pressure), and increasing salinity. Each 9000 mg/ℓ of salinity decreases oxygen solubility by approximately 5 percent of that of pure water (Boyd 1982).

Rates of oxygen consumption by aquatic organisms vary with species, size, activity, water temperature, nutritional status, and other factors. The oxygen consumption rates at 17-20°C for nine common species of freshwater fish ranged from 65 to 210 mg/kg/hr (Clausen 1936). The minimum concentration of dissolved oxygen tolerated by aquatic organisms is obviously a function of exposure time, but Swingle (1969) believed that fish would die if exposed for long periods to less than 0.3 mg/ℓ dissolved oxygen and that concentrations above 5.0 mg/ℓ were most desirable in fish ponds. Prolonged exposure to sublethally low concentrations of dissolved oxygen have been reported to decrease fry survival (Brungs 1971) and to decrease weight gain and feed consumption (Andrews et al. 1973) and is considered a precursor to bacterial infection in fish (Plumb et al. 1976).

Photosynthesis by phytoplankton is the primary source of dissolved oxygen in pond culture systems (Boyd 1979a). Photosynthesis during the daylight hours usually produces oxygen faster than it is used in respiratory processes in the pond, and dissolved oxygen levels will rise. Photosynthesis will cease at night while respiration by plankton, fish, and benthic organisms will continue, resulting in a nighttime decline in dissolved oxygen concentrations (Boyd et al. 1978a). During a 24-hr period, dissolved oxygen concentrations usually exhibit a marked fluctuation in pond culture systems, particularly when phytoplankton density is great (Figure 1). Boyd et al. (1979) reported that dissolved oxygen levels in commercial channel catfish (*Ictalurus punctatus*) ponds are regularly greater than 15 mg/ℓ in afternoons and less than 3 mg/ℓ in the morning.

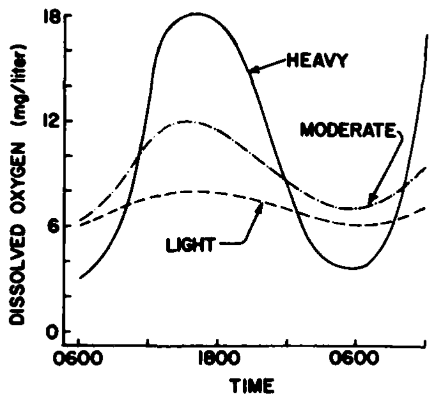


Figure 1. Diel fluctuations of dissolved oxygen concentrations in surface water of ponds with different densities of phytoplankton

Photosynthesis is reduced with decreasing solar radiation, while respiration is not appreciably affected. A period of overcast days can result in severe oxygen depletion in ponds (Figure 2). Romaire and Boyd (1979) reviewed the effects of solar radiation on dissolved oxygen concentrations in channel catfish ponds.

Mechanical aeration is an accepted means of increasing oxygen levels in ponds, and fish yields have been increased in ponds receiving nightly aeration (Hollerman and Boyd 1980). A complete discussion of aeration in pond culture systems is beyond the scope of this paper but may be found in Boyd (1982).

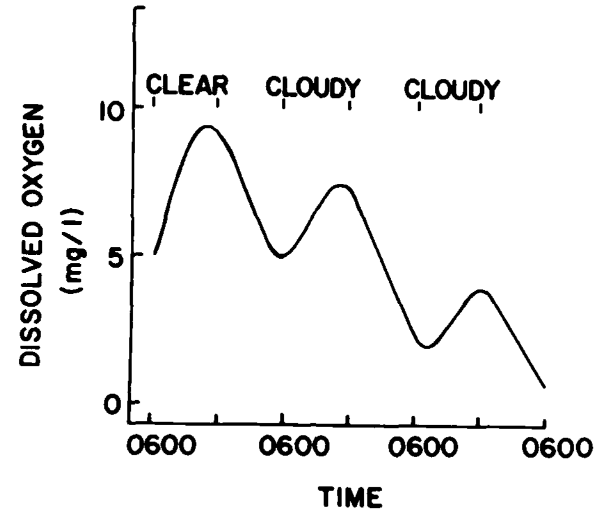


Figure 2. Effect of cloudy weather on dissolved oxygen concentrations in ponds (after Boyd 1979a)

CARBON DIOXIDE

Although greatly soluble in water, carbon dioxide comprises only a small portion of the atmosphere. It is not appreciably toxic to fish, which may survive in up to 60 mg/ℓ of free carbon dioxide provided dissolved oxygen is plentiful (Boyd 1979a). Doudoroff and Katz (1950) concluded that some fish species are very resistant to free carbon dioxide, while concentrations of 100 to 200 mg/ℓ can be rapidly lethal to more sensitive species in the presence of usually adequate dissolved oxygen concentrations. If dissolved oxygen levels are low, appreciable carbon dioxide hinders oxygen uptake by fish (Basu 1959). Some delicate marine species are apparently more susceptible to carbon dioxide than freshwater species, with 39 mg/ℓ being fatal to young herring (*Clupea pallasii*) within 160 min (Doudoroff and Katz 1950).

Carbon dioxide levels are usually greatest in early morning in ponds. As this is the same time when dissolved oxygen concentrations are typically lowest, it is sometimes desirable to remove carbon dioxide when concentrations exceed 10-15 mg/ℓ (Boyd 1982). Hansell and Boyd (1980) found an application of 1.68 mg/ℓ hydrated lime for each 1 mg/ℓ of carbon dioxide effective in removing carbon dioxide from water.

pH

As a measure of hydrogen ion activity, pH indicates whether water is acidic or basic in reaction. The pH of natural water is greatly influenced by the concentration of carbon dioxide (Boyd 1979a). As carbon dioxide is

utilized by aquatic plants during photosynthesis, hydrolysis of carbonate yields hydroxyl ions and pH rises.

In most waters carbonate and bicarbonate ions are associated with calcium and magnesium ions. The carbonate concentration increases during photosynthesis and the solubility product of calcium carbonate is exceeded. Calcium carbonate precipitation limits further increases in the pH as carbonate hydrolysis is the source of the hydroxyl ions. The pH on these waters will usually remain less than 9.5 or 10 in the afternoon.

In some fresh waters, however, the calcium concentration is much less than the carbonate and bicarbonate concentration. Sodium or, to a lesser extent, potassium is often exchanged for calcium in waters passing through aquifiers of marine origin. Sodium and potassium carbonates are much more soluble than calcium carbonate. Carbonates will accumulate in these waters during photosynthesis, and afternoon pH values may rise to 11 or 12. Swingle (1961) reported a pH of 11 as the akaline death point for warmwater pond fish (Figure 3).

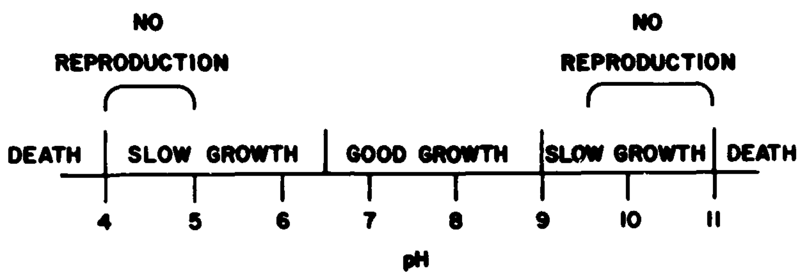


Figure 3. Effect of pH on pond fish
(after Swingle 1961)

Boyd et al. (1978b) reported that some ponds near the coast of South Carolina have alkalinities of 200-500 mg/ℓ and calcium hardnesses of less than 20 mg/ℓ. Dense phytoplankton blooms in these ponds cause pH values to occasionally rise to levels toxic to fish.

Agricultural gypsum ($CaSO_4 \cdot 2H_2O$) has been found effective in reducing high pH (Mandal and Boyd 1980). The agricultural gypsum supplies calcium ions to correct the difference between calcium hardness and total alkalinity levels. Boyd (1982) provides an equation for determining the required concentration of agricultural gypsum:

$$\text{Agricultural gypsum, in mg/}\ell = (\text{TA} - \text{CaH})\ (4.3)$$

where TA = total alkalinity and CaH = calcium hardness. Agricultural gypsum apparently has no adverse effects on aquatic organisms at concentrations up to those of a saturated solution, approximately 2000 mg/ℓ (McKee and Wolf 1963).

Application of some acid-forming fertilizers such as ammonium sulfate will also reduce the pH of water (Swingle 1961). This will do nothing to correct the cause of high pH, however, and levels of toxic un-ionized ammonia will be high following application of an ammonia salt to water (Boyd 1982).

AMMONIA

Ammonia may reach water from fertilizers and fish excrement. Ponds in which fish are receiving large amounts of supplemental feed may develop high concentrations of ammonia. Decomposition of nitrogenous material also contributes ammonia to pond waters.

Ammonia is present in water as both un-ionized ammonia (NH_3) and the ammonium ion (NH_4^+). These two forms exist in a pH- and temperature-dependent equilibrium. The proportion of total ammonia nitrogen in the un-ionized form increases with increasing pH and temperature (Table 1). Tables including additional temperature and pH values can be found in Trussell (1972), Emerson et al. (1975), and Boyd (1979a, 1982).

Table 1

Percentage of Total Ammonia Nitrogen Existing as Un-Ionized Ammonia in Waters of Different Temperatures and pH Values (After Boyd 1979a)

	Temperature, °C				
pH	16	20	24	28	32
7.0	0.30	0.40	0.52	0.70	0.95
7.4	0.74	0.99	1.30	1.73	2.36
7.8	1.84	2.45	3.21	4.24	5.72
8.2	4.49	5.94	7.68	10.00	13.22
8.6	10.56	13.68	17.28	21.83	27.68
9.0	22.87	28.47	34.42	41.23	49.02
9.4	42.68	50.00	56.86	63.79	70.72
9.8	65.17	71.53	76.81	81.57	85.85
10.2	82.45	86.32	89.27	91.75	93.84

Un-ionized ammonia is highly toxic to aquatic organisms while the ammonium ion is relatively nontoxic (Boyd 1982). The reported toxic concentrations of un-ionized ammonia nitrogen to fish range from 0.4 to 3.1 mg/ℓ (Ball 1967; Colt and Tchobanoglous 1976). Sublethal concentrations of un-ionized ammonia are reported to cause gill damage and poor growth in channel catfish (Robinette 1976).

There is no practical means of preventing the accumulation of ammonia in pond culture systems, but relatively high concentrations are often found in ponds where fish culture is profitable (Boyd 1982).

NITRITE

Nitrite accumulates in ponds from the oxidation of ammonia (Boyd 1979a) and the reduction of nitrate (Hollerman and Boyd 1980). It is absorbed by fish and reacts with hemoglobin to form methemoglobin, which is not an effective carrier of oxygen. Blood containing appreciable methemoglobin develops a characteristic brown color. Nitrite poisoning in fish is often referred to as "brown blood disease."

Tomasso et al. (1979a) reported that exposure of channel catfish fingerlings to 1, 2.5, and 5 mg/ℓ nitrite for 24 hr resulted in methemoglobin levels of 21, 60, and 77 percent, respectively. Nitrite levels of 0.5 mg/ℓ are toxic to certain coldwater fish (Crawford and Allen 1977). Sodium chloride and calcium chloride protect fish from nitrite toxicity, and a pond treatment of 25 mg/ℓ sodium chloride for each 1 mg/ℓ nitrite is recommended (Tomasso et al. 1979b).

CLAY TURBIDITY

Turbidity caused by colloidal clay particles will restrict light penetration of the water column and limit photosynthesis. Colloidal particles are extremely small (1-100 nm) and remain in suspension against the force of gravity. They generally carry a negative charge in water and repel one another.

The most effective technique for removing colloids from water is the introduction of electrolytes of opposite charge. The positively charged electrolyte neutralizes a portion of the negative charge of the colloid, permitting flocculation of the particles to occur. The floc of particles will become sufficiently heavy to allow precipitation.

Boyd (1979b) found filter alum (aluminum sulfate, $Al_2(SO_4)_3 \cdot 14\ H_2O$) extremely effective for removal of clay turbidity from fish ponds. The exact application rate of alum for a particular pond may be determined by treating samples of the pond water with concentrations of alum from 10 to 40 mg/ℓ in 5-mg/ℓ increments. The water samples are examined after 1 hr. The lowest alum concentration causing a floc of clay particles is the desired treatment rate. If the alum requirement test cannot be done, application of 25-30 mg/ℓ of filter alum will likely remove the clay turbidity from most waters (Boyd 1982). If insufficient alum is added, however, no precipitation of the colloid will occur.

Alum treatment will reduce alkalinity and pH values. If the alum requirement is greater than the total alkalinity, hydrated lime should be applied to the pond at a rate of 0.4 mg/ℓ hydrated lime for each 1 mg/ℓ alum (Boyd 1982). The hydrated lime and alum should not be mixed together prior to application, but they may be applied simultaneously. The alum should be dissolved in water and sprayed uniformly over the water surface during calm, dry weather.

CONCLUSIONS

Water quality problems in ponds become more common as aquaculture becomes more intensive. Increased stocking densities, supplemental feeding, and pond fertilization may increase production and profits, but undesirable environmental effects may also result. This is true for both traditional aquaculture operations and aquaculture in dredged material containment areas. The proper management of these water quality variables can easily be the difference between a successful and unsuccessful aquaculture operation.

There may also be water quality problems particular to containment area aquaculture sites. Dredged material may contain contaminants that can become bioavailable due to water quality changes. The complex interactions between the various regulatory mechanisms, sediment-water mechanisms, and contaminants may, however, make difficult the determination of exactly how a physiochemical change will influence this bioavailability (Gambrell et al. 1976). The final identification of water quality problems unique to aquaculture in containment sites and management methods to control those problems will only come as the result of research involving the various soil and water types found in dredged material containment areas across the country.

LITERATURE CITED

Andrew, J. W., Murai, T., and Gibbons, G. 1973. "The Influence of Dissolved Oxygen on the Growth of Channel Catfish," Trans. Amer. Fish. Soc., Vol 102, pp 835-838.

Ball, I. R. 1967. "The Relative Susceptibility of Some Species of Freshwater Fish to Poisons. I. Ammonia," Water Res., Vol 1, pp 767-775.

Basu, S. P. 1959. "Active Respiration of Fish in Relation to Ambient Concentrations of Oxygen and Carbon Dioxide," J. Fish. Res. Bd. Canada, Vol 16, pp 175-212.

Boyd, C. E. 1979a. "Water Quality in Warmwater Fish Ponds," Auburn University Agricultural Experiment Station, Auburn, Ala.

Boyd, C. E. 1979b. "Aluminum Sulfate (Alum) for Precipitating Clay Turbidity from Fish Ponds," Trans. Amer. Fish. Soc., Vol 108, pp 307-313.

Boyd, C. E. 1982. Water Quality Management for Pond Fish Culture, Elsevier Scientific Publishing Company, Amsterdam, The Netherlands.

Boyd, C. E., Romaire, R. P., and Johnston, E. 1978a. "Predicting Early Morning Dissolved Oxygen Concentrations in Channel Catfish Ponds," Trans. Amer. Fish. Soc., Vol 107, pp 484-492.

Boyd, C. E., Preacher, J. W., and Justice, L. 1978b. "Hardness, Alkalinity, pH, and Pond Fertilization," Proc. Annual Conf. Southeast. Assoc. Fish and Wildl. Agencies, Vol 32, pp 605-611.

Boyd, C. E., Steeby, J. A., and McCoy, E. W. 1979. "Frequency of Low Dissolved Oxygen Concentrations in Ponds for Commercial Culture of Channel Catfish," Proc. Annual Conf. Southeast. Assoc. Fish and Wildl. Agencies, Vol 33, pp 591-599.

Brungs, W. A. 1971. "Chronic Effects of Low Dissolved Oxygen Concentrations on the Fathead Minnow (*Pimephales promelas*)," J. Fish. Res. Bd. Canada, Vol 28, pp 1119-1123.

Clausen, R. G. 1936. "Oxygen Consumption in Freshwater Fishes," Ecology, Vol 17, pp 216-226.

Colt, J., and Tchobanoglous, G. 1976. "Evaluation of the Short-Term Toxicity of Nitrogenous Compounds to Channel Catfish, *Ictalurus punctatus*," Aquaculture, Vol 8, pp 209-224.

Crawford, R. E., and Allen, G. H. 1977. "Seawater Inhibition of Nitrite Toxicity to Chinook Salmon," Trans. Amer. Fish. Soc., Vol 106, pp 105-109.

Doudoroff, P., and Katz, M. 1950. "Critical Review of the Literature on the Toxicity of Industrial Wastes and Their Components to Fish. I. Alkalies, Acids, and Inorganic Gases," Sewage and Industrial Wastes, Vol 22, pp 1432-1458.

Emerson, K., Russo, C., Lund, R., and Thurston, R. V. 1975. "Aqueous Ammonia Equilibrium Calculations: Effects of pH and Temperature," J. Fish. Res. Bd. Canada, Vol 32, pp 2379-2388.

Gambrell, R. P., Khalid, R. A., and Patrick, W. H. 1976. "Physiochemical Parameters That Regulate Mobilization and Immobolization of Toxic Heavy Metals," P. A. Krenkel, J. Harrison, and J. C. Burdick III (eds.), Proceedings of the Specialty Conference on Dredging and Its Environmental Effects, American Society of Civil Engineers, New York, pp 418-434.

Hansell, D. A., and Boyd C. E. 1980. "Uses of Hydrated Lime in Fish Ponds," Proc. Annual Conf. Southeast. Assoc. Fish and Wildl. Agencies, Vol 34, pp 49-58.

Hollerman, W. W., and Boyd, C. E. 1980. "Nightly Aeration to Increase Production of Channel Catfish," Trans. Amer. Fish. Soc., Vol 109, pp 446-452.

Mandal, B. K., and Boyd, C. E. 1980. "Reduction of pH in Waters With High Total Alkalinity and Low Total Hardness," Prog. Fish-Cult., Vol 42, pp 183-185.

McKee, J. E., and Wolf, H. W. (eds.). 1963. Water Quality Criteria, 2nd ed., State of California, Publication No. 3-A, State Water Quality Control Board, Sacremento, Calif.

Plumb, J. A., Grizzle, J. M., and DeFigueriredo, J. 1976. "Necrosis and Bacterial Infection in Channel Catfish (*Ictalurus punctatus*) Following Hypoxia," J. Wildl. Diseases, Vol 12, pp 247-253.

Robinette, H. R. 1976. "Effect of Selected Sublethal Levels of Ammonia on the Growth of Channel Catfish (*Ictalurus punctatus*)," Prog. Fish-Cult., Vol 38, pp 26-29.

Romaire, R. P., and Boyd, C. E. 1979. "Effects of Solar Radiation on the Dynamics of Dissolved Oxygen in Channel Catfish Ponds," Trans. Amer. Fish. Soc., Vol 108, pp 473-478.

Swingle, H. S. 1961. "Relationships of pH of Pond Waters to Their Suitability for Fish Culture," Proc. Pacific Sci. Congress, Vol 9 (1957), No. 10, pp 72-75.

Swingle, H. S. 1969. "Methods of Analysis for Waters, Organic Matter, and Pond Bottom Soils Used in Fisheries Research," Auburn University, Auburn, Ala.

Tomasso, J. R., Simco, B. A., and Davis, K. B. 1979a. "Chloride Inhibition of Nitrite-Induced Methemoglobinemia in Channel Catfish (*Ictalurus punctatus*)," J. Fish. Res. Bd. Canada, Vol, 36, pp 1141-1144.

__________. 1979b. "Inhibition of Ammonia and Nitrite Toxicity to Channel Catfish," Proc. Annual Conf. Southeast. Assoc. Fish and Wildl. Agencies, Vol 33, pp 600-605.

Trussell, R. P. 1972. "The Percent Un-Ionized Ammonia in Aqueous Ammonia Solutions at Different pH Levels and Temperatures," J. Fish. Res. Bd. Canada, Vol 29, pp 1505-1507.

HEALTH AND DISEASE CONTROL FOR AQUATIC ANIMALS IN DREDGED MATERIAL CONTAINMENT SITES

by
S. Ken Johnson
Fish Disease Specialist
Texas A&M University
College Station, Texas 77843

ABSTRACT

Several common diseases of coastal fishes should play an important role in aquacultures that utilize dredged material containment sites. Circumstances that develop from increased stock density should favor crustacean parasites and parasites with simple life cycles. Climate extremes and abrupt changes are apt to predispose microbial disease and water enrichment will favor oxygen shortage and epiboint fouling. Potential corrective measures are noted.

INTRODUCTION

Dredged material containment sites that have been modified for aquaculture have unique characteristics that could influence the prevalence of aquatic animal disease: (1) numerous animals in a confined area, (2) weather influences on water quality extremes, and (3) progressive enrichment of culture water. This paper will place emphasis on the health and disease of coastal fishes and crustaceans.

The presence of numerous animals in a confined area enhances the opportunity for numerical development and host contact of parasites, particularly those with simple life cycles. Parasites with complex cycles may also flourish in confined areas if required additional hosts are present in the culture system. Of great importance to marine fishes are crustacean parasites and certain protozoa. Helminth, or worm parasites, are not as important for marine fish health but may be important in product acceptance by human consumers.

Crustacean parasites are perfectly capable of increasing numbers in containment site ponds. Copepods of the genus *Ergasilus* and certain caligoid copepods have been a consistent problem to finfish mariculture. Members of the Branchiura, commonly called "fish-lice," are widespread on fishes of coastal waters. Also, isopods have been noted of importance in marine finfish, primarily when infesting fishes in cage or net-pen culture. Practical control of crustacean parasites would potentially include the use of

pesticides such as Dylox, Bromex, and Malathion (Sarig 1971) but these chemicals do not have regulatory agency approval for use in marine aquaculture. Noteworthy protozoan parasites of marine fish include *Trichodina* and *Amyloodinium*. In containment sites practical control of these parasites consists of reducing stocking densities and improving environmental conditions.

The incidence of internal helminth parasites of coastal fish is high because of migratory buildup of numbers of water birds along the coastal areas. Infesting agents are typically nematodes and trematodes. There is no effective control for this situation in large containment sites. In shrimp culture, required alternate hosts usually are not present and helminth parasitism is of little importance. Where mollusks are present with shrimp in ponds there is normally a buildup of gregarine protozoans, members of which develop in shrimp intestines and may cause blockage of the digestive tract. Control consists of periodic drying of culture ponds to rid them of mollusks.

Confinement increases potential for detrimental effects of toxins produced by certain algae. These blooms can affect both finfish and crustacea. Management includes surveillance, water exchange, and use of ammonia sulfate or other chemicals as herbicides.

WEATHER INFLUENCES ON WATER QUALITY EXTREMES

Crustacean culture in impoundments is considered a seasonal effort on our southern coastline. Fish culture is not as severely affected. Nevertheless, of fishes that survive in a weakened state, sudden temperature drops in winter result in fish kills and widespread fungal infections in confined fishes. Chemical control for fungus in these conditions is not suggested because of prolonged presence of chemical residue in the cold water.

Water temperatures above 30°C are prone to support development of bacterial diseases, particularly *Vibrio*. Water exchange or circulation during cool hours may be beneficial in certain circumstances. Reduction of bacterial numbers by oxidizing agents has some potential (Phelps et al. 1977), but the positive benefit of the use of antibacterial agents in the food of marine animals has not been adequately established.

The rainy season on the gulf coast can result in deterioration of suitable culture environments by producing combinations of low water salinity and high temperatures (Holt and Strawn 1977). Fishes as well as shrimps are frequently predisposed to disease in such circumstances. Management decisions would include site selections capable of providing suitable salinities in rainy periods.

Winds blow intermittently along the coast and heavy winds have the potential of stirring up bottom sediments (Paperna and Overstreet 1981). Water chemistry changes and often sudden increases in temperature may cause conditions capable of weakening animals and predisposing them to disease.

PROGRESSIVE ENRICHMENT OF CULTURE WATER

Aside from the enhanced potential for an increase in numbers of harmful bacteria, modification of the culture environment by enrichment can lead to oxygen shortage and increased abundance of fouling organisms. Oxygen shortage is probably the most important predisposing factor to disease in summer grow-out. Management by aeration is used in most aquacultures where progressive enrichment occurs. Water exchange methods are also essential in summer grow-out of crustacean crops.

Fouling organisms, or epibionts, increase in numbers in enriched cultures as they fill an important niche in the decomposition process. Filamentous bacteria and sessile protozoa are agents that commonly coat the surfaces of crustaceans. When abundant, they can interfere with their host's respiration. Water exchange methods have been noted to relieve this problem (Johnson 1978).

SUMMARY

In summary, containment sites have characteristics which favor certain health and disease abberations. Confinement in numbers favors development of parasites with direct cycles such as copepods and protozoa, and those with more complex cycles that require the presence of hosts such as migratory birds. Confinement also enhances the threat of toxic algae.

Water quality extremes caused by weather influences can enhance possibilities for fungal and bacterial disease as well as decline in stock condition. Progressive enrichment favors oxygen shortage as a predisposing factor of disease, particularly bacterial, and also favors the increase of fouling organisms on surfaces of cultured animals, particularly crustaceans.

LITERATURE CITED

Holt, R., and Strawn, K. 1977. "Cage Culture of Seven Fish Species in a Power Plant Effluent Characterized by Wide Salinity in Fluctuations," Proc. 8th Ann. Meeting World Mariculture Society, San Jose, Costa Rica, pp 73-90.

Johnson, S. K. 1978. "Some Disease Problems in Crawfish and Freshwater Shrimp Culture," Proc. 1978 Fish Farming Conference, Texas A&M University, College Station, Tex.

Paperna, I., and Overstreet, R. M. 1981. "Parasites and Diseases of Mullets (Mugilidae)," Aquaculture of Grey Mullets, O. H. Oren, ed., International Biological Programme 26, Cambridge Univ. Press, Cambridge, pp 441-493.

Phelps, R. P., Plumb, J. A., and Harris, C. W. 1977. "Control of External Bacterial Infections of Bluegills With Potassium Permanganate," Progressive Fish Culturist, Vol 39, pp 143-144.

Sarig, S. 1971. "The Prevention and Treatment of Diseases of Warmwater Fishes Under Subtropical Conditions, With Special Emphasis on Intensive Fish Farming," Diseases of Fishes, S. F. Snieszke and H. R. Axelrod, eds., T. F. H. Publications, Inc., Ltd, Hong Kong.

AD P002139

POND DESIGN AND MANAGEMENT FOR COASTAL AQUACULTURE

by
R. Vernon Minton
Marine Resources Division
Alabama Department of Conservation
and Natural Resources
Claude Peteet Mariculture Center
Gulf Shores, Alabama 36542

R. Vernon Minton

ABSTRACT

Pond design and layout will ultimately determine the degree to which a pond can be managed. Preliminary survey of a prospective site should include soil analysis for water retention capabilities. Promising sites with permeable soils can sometimes be sealed to reduce water loss by mechanical means or through the addition of materials which form an impermeable blanket.

The size of a pond is determined by many variables, including the topography of the land, available capital, construction expense, market demand of the product being cultured, and available labor. The pond bottom should slope toward the drain location with a minimum ratio of 1:1000. Harvest areas, or catch basins, are recommended for production ponds and should comprise approximately 10 percent of the pond area or be large enough to maintain the pond production during the harvest operation.

Intake water should be filtered to prevent entry of predator or competitor species into production ponds. Pond use, filling and drainage, and chemicals and fertilizers added to the pond should be kept as part of the permanent record for each pond. Minimum water quality parameters such as temperature, salinity, and oxygen should be monitored. Systematic pond preparation of each pond should be made prior to stocking of either larval or fingerling fish. Rotenone at a concentration of 4 mg/ℓ should be added to any water remaining in the harvest area to eliminate wild fish or fish from the previous culture period. Present information on fertilization in brackish water ponds is quite limited. Chicken manure has thus far given the best returns from fingerling production ponds at the Claude Peteet Mariculture Center.

INTRODUCTION

The future expansion of mariculture will depend largely on the ability of design engineers to construct fish ponds in areas unsuitable for other agricultures or commercial or private dwellings. Dredged material containment sites may provide an excellent opportunity to expand mariculture and utilize land unsuitable for other ventures at the same time. However, each site must be approached individually considering not only the needs of the species to be cultured but also the need to take advantage of the topography of the site. The layout and design of a pond system will ultimately determine the degree to which it can be managed. The geographical location and its accessibility will dictate species selection and marketability of the product. The ability to manage the water, both in filling and draining as well as during the culture period, will enhance the production potential of the pond and allow the manager more flexibility in stocking and harvest times. Although brackish water ponds have traditionally been built in low lying, poorly drained areas, the original design and layout of the pond system should include the capability of draining each pond separately at any given time. Partial harvest of the crop can be accomplished through seining or trapping; however, the margin of profit will most likely be consumed in additional labor expenses or left unharvested in the pond.

Preliminary Survey

Initial survey of a potential pond site should include soil analysis for water retention capabilities. Core samples of the soil should be taken in a cross section of the area at 50- to 100-m intervals in a grid pattern to a depth of 2 m and analyzed for clay, sand, and humus content. Clay content should be greater than 20 percent and seepage rate tests should show a water loss of less than 10 cm from a 15-cm-diam hole in 24 hours. Promising sites with permeable soils can sometimes be sealed to maintain acceptable water losses. The methods used depend largely on the proportions of coarse-grained sand and gravel and of fine-grained clay and silt in the soil. Suggested methods are described in detail in the U. S. Soil Conservation Service Handbook No. 387 (1971). Compaction of an area which contains sufficient clay but a wide range of particle sizes of gravel, sand, and silt will control seepage. The area to be sealed is first scarified with a disk or rototiller and then rolled to a tight layer with four to six passes with a sheepsfoot roller. When insufficient clay is available at the site, high quality clay can be hauled into the area to form an impermeable blanket. The minimum thickness recommended is 30 cm for depths of water up to 3 m. The material is spread evenly in 15-cm layers and then compacted with four to six passes with a sheepsfoot roller. The compacted blanket should be covered with approximately 30 cm of soil or fine gravel to prevent cracking and rupture from drying and freezing. Bentonite, a fine-textured colloidal clay, is sometimes used to seal ponds which are not drained at regular intervals. When wet, bentonite can swell as much as 20 times its original volume and form an effective seal between coarse sand or gravel particles. However, upon drying it returns to its original volume, a property which essentially eliminates its use in production ponds.

Chemical additives, though sometimes effective in sealing ponds, should be approached with extreme caution. Although apparently nontoxic to fish,

they may inhibit zooplankton production and severely affect fingerling production. A commercially available tar-like substance was tested at the Claude Peteet Mariculture Center (CPMC) in 1976. The nontoxic product was used in an attempt to seal ponds scheduled for striped bass fingerling production. Although the ponds had good zooplankton populations throughout the culture period, at harvest, fingerlings showed obvious signs of malnutrition (Powell 1977).

Pond Size

The size of the culture pond is determined by many variables, including the topography of the land, available capital, construction expense, market demand of the product being cultured, and available labor. Small ponds are generally more manageable than large ponds, but the increased cost of dike construction generally prohibits their use. Certain features, regardless of size, should be incorporated into each pond. They should be sloped to facilitate drainage; the degree of slope will be determined by the crop cultured. The pond bottom should slope toward the drain location with a minimum ratio of 1000:1 (horizontal to vertical). Higher slope ratios are preferable, ranging from 1000:3 to 1000:6, unless crops of fingerling fish or shrimp are anticipated where steep, fast-draining slopes would leave these crops stranded.

A harvest area, or catch basin, is recommended for production ponds, whether the produce is to be sold live or processed. The basin should be 45-60 cm deeper than the remainder of the pond, preferably with the sides and bottom reinforced with wood or concrete to prevent sluffing. Basins can be constructed in clay bottoms, but frequent maintenance is required. The catch basin should comprise approximately 10 percent of the pond area or be large enough to maintain the pond production during the harvest operation.

Drain lines and structures should be sized to allow rapid drainage and harvest. The 0.08-ha ponds at CPMC are equipped with 15.2-cm PVC drainage standpipes. Water level and drainage are accomplished by rotating the pipe on a threaded PVC coupling. The design and operation of this type structure have proven efficient and economical for the variety of crops cultured at CPMC.

Water inlet lines should be positioned at the drainage end of the pond and over the catch basin. Water intake lines should be slightly larger than estimated for normal water management requirements since screening materials used to filter out unwanted organisms from the water supply reduce water flow. The use of monk structures with fill and drain canals where tidal fluctuations are sufficient to both fill and drain ponds are, unfortunately, not practical along the northern Gulf of Mexico. Here water must be lifted into ponds with mechanical pumps. At CPMC, a 15-cm-suction, 10.2-cm-discharge, 30-cm-impeller Berkley saltwater pumping unit has been employed. The pump is coupled to a 50-hp electric motor and is rated to deliver 1,000 gal/min at 42.7 m total head. It has proven adequate to supply 35 0.08-ha research and production ponds. The unit is constructed of cast iron and has given reliable online service life of approximately 4 years.

Main water supply lines are 15.3-cm PVC pipes which are reduced to 10.2-cm inlet lines for each pond. Valves made of cast iron, anodized aluminum, and brass have been used at CPMC. However, due to cost and extensive maintenance required to keep the valves free, we opted for PVC valves. We have used Asahi 10.2-cm ball valves for approximately 2 years with good results.

Predator-Competitor Control

Since most sources for brackish water supply contain wild fish, the water must be screened to prevent the entry of either predator or competitor fishes. Several types of screening material are available. Saran screen (National Filter Media Corp., New Haven, Connecticut) has been employed at various freshwater and brackish water production and research stations (Sills 1968). The material can be purchased in a variety of mesh sizes which allow for maximum water flow. A drawback of Saran is that it does break down under ultraviolet radiation. Due to this property and its expense, we opted for a tubular nylon webbing (Domestic Lace Mgf., Inc., Style ES-884523). The product (mesh size 300 μ), similar to encasement sleeve found on fire hose, is sold in a variety of sizes. Use of the product only entails cutting to the desired length, tying one end and securing the other over the inlet pipe with a stainless steel hose clamp. The webbing has been effective in controlling unwanted fish species and has a pond life of approximately 4 to 5 months. Silt, debris, and periphyton will occasionally clog the material. Shaking periodically or removal and washing in an ordinary washing machine will extend the use of the material.

Pond Monitoring and Monitoring Records

In the operation of any facility, whether for research or commercial production, certain physical and chemical water quality parameters should be monitored and records kept to aide in future management decisions. A log of pond use, filling and drainage dates, and chemical and fertilizers added to the pond should be kept as part of the permanent record for each pond. Ponds built side by side, treated the same way, will in many cases vary tremendously in the production of similar crops. Water quality management can only take place after a thorough analysis of the principal water quality parameters in each pond over an extended period of time. Since water quality is to be covered in another section, only temperature, salinity, and oxygen will be discussed here.

Temperature. Water temperature probably has more influence on both the fish and other water quality parameters than any other single factor. At a particular point in time, it will influence fish behavior in spawning and feeding, subsequent growth, oxygen concentration, and ability of the pond to break down a given organic load. Records of temperature allow the manager to predict stocking and harvest times, predict periods where oxygen levels may fall dangerously low, and adjust feeding rates. Electronic continuous monitoring charts are useful for research centers, but maximum-minimum thermometers have proven, in the long run, to be of more practical value. Thermometers placed in strategic areas in the pond system allow the manager to monitor pond groups and general temperature changes due to recent fillings or changes in the local weather conditions.

Salinity. Salinity has been defined as the total amount of solid material in grams contained in one kilogram of seawater when all the carbonate has been converted to oxide, the bromine and iodine replaced by chlorine, and all organic matter completely oxidized. Although chemical measurement of salinity is available through titration to determine the chlorinity of the sample, then converting to salinity through use of the formula $S = 1.80655\ (Cl)$, most measurements are made with a salinometer that measures the electrical conductivity and temperature of the sample or by refractometers which are

temperature compensated with direct readout in parts per thousand salinity (American Optical and Sargeant Welch Co., Inc.).

Most of the fish species cultured thus far at CPMC have been estuarine in nature and euryhaline. Abrupt changes in salinity can cause mortality, reduce feeding, or, even in the hardiest of species presently cultured, reduce spawning. Some offshore species and all of the penaeid shrimp have very narrow salinity tolerances, especially in their early life stages. Slow acclimation will often enable the culture of stenohaline species in waters lower in salinity than found in their natural habitat. Salinity readings for waters at CPMC vary from 3 to 26 ppt depending on the season. Records kept over a period of years enable the prediction of expected seasonal salinity changes, and, therefore, enhance pond management. Unfortunately, a manager has little control over the salinity of incoming water, but, with good records, he can delineate periods of greatest risk and schedule the stocking of stenohaline species accordingly.

Oxygen. Oxygen is the most important dissolved gas in pond waters from the viewpoint of the fish culturist. Oxygen is essential for the well being of both fish and fish food organisms. There are two main sources of oxygen for pond waters, the atmosphere and green plants (Snow et al. 1964). Pond waters are often supersaturated with dissolved oxygen during the early hours of the night; however, due to oxygen demand as a result of the respiration of plankton and bacteria (biochemical oxygen demand) and chemical oxygen demand, early morning oxygen levels may be critically low.

Monitoring of oxygen levels can be accomplished through chemical analysis (American Public Health Association 1971) or through the use of polargraphic oxygen meters. Due to the rapidity in which pond oxygen levels must be determined, dissolved oxygen meters are recommended. Dissolved oxygen concentration should be monitored regularly in the late afternoon and early morning (preferably prior to sunrise). A log of oxygen concentrations will allow the manager to predict potential low concentrations and prepare for emergency measures.

Lethal and sublethal concentrations of dissolved oxygen vary among species of fish cultured and the size of the fish. Even though studies have shown that metabolic rate varies inversely with the size of the fish, smaller fish are able to withstand lower levels of dissolved oxygen than larger fish due to their ability to come to the surface and respire surface water which contains more oxygen. Prolonged sublethal oxygen levels will reduce growth rate, affect reproduction, and increase susceptibility of fish to disease.

Ponds with low dissolved oxygen concentrations can be temporarily corrected through mechanical agitation (Soderberg 1982) or by flushing the pond by pumping water into the pond. During flushing, waters from the pond should be removed from the bottom when possible. Feeding should be reduced or stopped altogether until normal oxygen levels return.

Pond Preparation

Systematic preparation of each pond should be made prior to stocking of either larval or fingerling fish. Special care should be taken to eliminate any wild fish present in the pond or fish from the previous culture period. At the CPMC, we routinely use Noxfish (McCrary's Farm Supply, Lonoke, Ark.), a liquid form of rotenone containing 5% derris root. A solution of the compound is mixed to form a concentration of approximately 4 mg/ℓ in the catch basin

area and spread in any puddles of water remaining in the pond after draining. Due to the hardiness of some of the estuarine fish eggs, it is also advisable to allow the pond to thoroughly dry prior to refilling. The rotenone should be detoxified by adding potassium permangenate at a concentration double that of the rotenone prior to refilling the pond. During the predator-competitor control operation, the dikes should be inspected for damage and evidence of crab burrows. If an abundance of mud crabs (*Xanthidae*) are found, the pond should be refilled and Baytex (McCrary's Farm Supply, Lonoke, Ark.) added at a concentration of 64 ppb. Low areas, or areas which drain poorly, should be filled in. Inlet valves should be checked for ease of operation and maintenance on plumbing performed if necessary.

Information on fertilization in brackish water ponds is quite limited (Johnson 1954; Bardach et al. 1972; De Los Santos 1978). At CPMC we have tried a variety of organic fertilizers including manure, meat scraps, fresh hay, and alfafa pellets for fingerling production and have found chicken manure to give the highest and most consistent results. The manure is applied at a rate of 450 kg/ha for the initial application and approximately 200 kg/ha at a 7- to 8-day interval during the culture period. The manure is either spread evenly around the shallow areas of the pond or placed in small piles, depending on the water temperature. Since degradation and entry of the manure into the pond ecosystem is temperature-dependent and varies with the surface area exposed, decomposition of the manure can be somewhat controlled to suit the needs of the production crop and the time of year. In order to initiate a quick zooplankton pulse in the spring with water temperatures of approximately 22°C, the manure is spread evenly in the shallow end of the pond. In mid-summer, when temperatures may approach 31°C, the manure is piled in order to slow decomposition. Rapid decomposition of any manure may create a situation of low dissolved oxygen. It is therefore advisable to monitor predawn oxygen levels for two to three consecutive days prior to stocking.

At CPMC, ponds to be stocked with fingerling fish to be grown to market size are fertilized at only one half the above rate or not at all if the pond has recently been drained. Nutrients released from uneaten or undigested feed and feces provide adequate fertilization.

In order to enhance zooplankton production, fingerling production ponds at CPMC are slow filled utilizing the puddle technique. After fertilization, water is added to cover approximately three fourths of the pond bottom. Once this level is reached, water is added only to replace losses due to seepage or evaporation. At stocking, water is slowly added to allow pond filling over the culture period. This technique, if properly used, allows the zooplankton population to continually expand and meet the needs of the growing fish (Powell 1976).

In fingerling production ponds, it is critical that the manager monitor zooplankton type and abundance. Although time-consuming, a knowledge of the pond dynamics and succession of pond organisms is the basis for proper management. Information on the pond zooplankton community will allow for the stocking of larvae when optimal numbers of appropriate zooplankton are available which will enhance survival and provide for increased production.

A plankton net should be used to sample ponds prior to stocking and during the culture period. Procedures used generally follow those recommended by the American Public Health Association (1971). A 15.2-m oblique tow is

made through the pond and the sample is preserved. At CPMC we use 5% formalin buffered with borax (approximately 1 tablespoon/liter) as a preservative. However, several other fixatives and preservatives are available (Gosner 1971) to meet specific needs. Sampling should occur at regular intervals at approximately the same time each day. Organism type and abundance are grouped in general classifications as rotifers, copepods, or cladocerans. In some situations, further breakdown into genus and species may be required. It is important to not only note the type of organisms present, but also their approximate sizes (nauplii, adults, etc.) and abundance. Stocking of larval fish should be scheduled to coincide with peak abundance of organisms of a size suitable for ingestion by the stocked larvae. Data compiled on each pond should become part of its permanent record to be used by the manager when deciding which pond to stock and when it should be stocked.

Stocking Procedures

Larval fish and shrimp in brackish water generally require more care in handling and stocking than do freshwater species. At CPMC acclimation to temperature and salinity changes generally proceed at a maximum rate of 2°C or 2 ppt salinity per hour for sensitive larval species, especially if the stocking water has higher temperature and lower salinity than that of the holding water. Rate of acclimation generally increases as the size of fish increases.

Accurate counts of larvae prior to stocking are critical to final evaluation of the crop and essential to future stocking considerations. Unfortunately, due to their small size, accurate enumeration of marine larvae is quite difficult. Several methods are available (Bonn et al. 1976) and it is advisable that the manager and his staff try different methods prior to establishing a standard for their use.

At CPMC larval holding units have premeasured volumes marked on the side of the container. Water level is siphoned to the known level and the concentrated fry slowly stirred to prevent clumping. Ten random 100-ml samples are taken for counting. Depending on the degree of variation between samples, additional samples may be taken. The counts are averaged and then extrapolated to produce an estimate for each holding unit. In order to adjust the number of larvae in each unit to accomodate the required stocking rates, larvae are added or deleted by visual comparison with a known number of larvae. It is important to randomly sample each lot of fry to ensure that the estimates are within the prescribed limits for error.

Acclimation of the larvae should begin and proceed to allow stocking shortly after sundown or prior to sunrise. Severe mortalities can occur if fry or postlarval shrimp are exposed to even short periods of ultraviolet radiation.

Harvest of fingerling fish should similarly begin prior to sunrise. It is advisable to have personnel on duty to monitor pond drainage and keep avian predators away from the crop. Oxygen concentrations in the catch basin area should be monitored, or personnel trained to recognize fish in stress should be available to ensure that the crop is not lost prior to harvest. After harvest, enumeration of the crop is made by sample counting known weights of fish, then extrapolating to the total weight of the crop.

CONCLUSIONS

Engineers must work closely with research biologists and extension personnel in analysis of the knowledge of the species to be cultured prior to initiation of design and construction of the pond system. The production of food fish or bait fish will require different pond designs which will ultimately allow for optimal management and subsequent maximized production. Research biologists must continue to expand present knowledge on culture species and culture techniques to allow the manager a margin of profit which will be greater than present or alternative uses of the land.

LITERATURE CITED

American Public Health Association, American Water Works Association, and Water Pollution Control Federation. 1971. Standard Methods for the Examination of Water and Wastewater, 13th ed., APHA, Washington, D. C.

Bardach, J. E., Ryther, J. H., and McCarney, W. O. 1972. Aquaculture: The Farming and Husbandry of Freshwater and Marine Organisms, Wiley Interscience, New York.

Bonn, E. W., Bailey, W. M., Bayless, J. D., Erickson, K. E., and Stevens, R. E. 1976. "Guidelines for Striped Bass Culture," Southern Div. Am. Fish Soc.

De Los Santos, C., Jr. 1978. Modern Aquaculture for the Philippines, Yuhum La Defensa Press, Iloilo City, Philippines.

Gosner, K. L. 1971. Guide to Identification of Marine and Estuarine Invertebrates, John Wiley and Sons, New York.

Johnson, M. C. 1954. "A Suggested Inorganic Fertilizer for Use in Brackish Water," Quarterly Journal of the Florida Academy of Sciences 17(2):119-127.

Powell, M. R. 1976. "Two Years of Brackish Water Pond Culture of Striped Bass (*Morone saxatilis*) in South Alabama," Proceedings of the Seventh Annual Meeting World Mariculture Society, pp 93-97.

Powell, M. R. 1977. "Striped Bass Production and Stocking Experiments in Alabama Coastal Areas," Alabama Department of Conservation and Natural Resources, Marine Resources Division, Federal Aid Annual Progress Report, AFCS-11-1.

Sills, J. B. 1968. "Saran Screen Fish Barrier," U. S. Fish Farming Experiment Station, Stuttgart, Ark. (Mimeo).

Soderberg, R. W. 1982. "Aeration of Water Supplies for Fish Culture in Flowing Water," Prog. Fish-Cult. 44(2):89-93.

Snow, J. R., Jones, R. O., and Rodgers, W. A. 1964. "Training Manual for Warm Water Fish Culture," Bureau of Sport Fisheries and Wildlife Warmwater Inservice Training School, Marion, Ala. (Mimeo).

U. S. Soil Conservation Service. 1971. "Ponds for Water Supply and Recreation," Department of Agriculture, Handbook No. 387.

MARICULTURE IN OLD RICE FIELD IMPOUNDMENTS: AN ANALOGY FOR DREDGED MATERIAL CONTAINMENT AREAS

by
John M. Dean, Charles A. Wilson,
and Noel C. Alon
Belle W. Baruch Institute for Marine
Biology and Coastal Research
University of South Carolina
Columbia, South Carolina 29208

John M. Dean

ABSTRACT

Thousands of acres of South Carolina's estuarine coastline were impounded for rice production before the start of the twentieth century. This acreage, owned by private concerns, State agencies, and the Federal government, has been used for extensive aquaculture production since rice cultivation was abandoned. The most common use has been active management for waterfowl, and significant returns have been realized from hunting leases. Historically, a variety of organisms of interest to aquaculturists have been introduced into the ponds. Our research has shown that blue crabs, mullet, and shrimp survive at a higher rate and grow larger than do their "wild" counterparts. Additional studies have indicated that cage-grown oysters are also adaptable to rice-field culture. Other species, such as bait minnows, clams, and scallops, could be raised in the brackish water impoundments while prawns and crawfish would be suitable for freshwater impoundments. Experimental aquaculture has, so far, been limited to a very low management extensive type of culture. Dredged material containment areas (DMCA) would do better to combine intensive and extensive cultures. Existing impoundment aquaculture provides a management model, while the development and success of DMCA aquaculture would contribute to solving current impoundment problems.

INTRODUCTION

We would like to discuss with you some work we have done over the past several years in old rice field impoundments in South Carolina. We will present the results that we have had with work on blue crabs, oysters, crawfish, shrimp, and certain species of fish; some comments on waterfowl; observations on impoundment biology; some thoughts on future directions for work in these systems; and considerations of aquaculture in dredged material containment areas (DMCA).

Some aspects of the history of the coast of South Carolina clearly put us in a slightly different situation than most of the country. We have had large coastal impoundments for many years. The coast of South Carolina was the leading producer of rice in the United States up to the Civil War. In fact, 90% of the rice in South Carolina came out of one county, Georgetown County. An aerial view of the coast shows extensive acreage of old rice field impoundments along the coastal river systems (Figure 1).

Thus, in South Carolina, we have privately managed impoundments that have been so for hundreds of years, impoundments managed by the State Wildlife and Marine Resources for wildlife habitat and public waterfowl shooting, and the Corps of Engineers owned and leased impoundments. The literature on this has recently been very well reviewed by Miglarese and Sandifer (1982).

The impoundments that once were used for cultivation of rice are now extensively used and managed for waterfowl (Figure 1). It has only been in the past few years that we have looked at these for potential utilization for other economic activities. Much of this information is available in more detail elsewhere (Dean 1975).

In the process of maintaining these systems, the manager of the plantation often had to rebuild the levees. In the process of rebuilding the levees, the fields were drained and dried out for up to three years. The drying process led to the formation of cat clays, and upon reflooding the fields the water had a pH of 2. We determined that it took about three years for the systems to recover, but they became as productive as they ever were.

Many old rice fields are currently managed for ducks. The central area of each field is covered with cordgrass (*Spartina alterniflora*) or widgeon grass (*Ruppia maritima*) and surrounded by a peripheral canal from which the dirt was taken for the levees. The water control structures are of modern construction, but they have the same design and functionally operate in the same manner as those that were constructed in the mid-19th century for rice cultivation (Doar 1936).

The previous papers in this meeting have emphasized the contrast between sophisticated intensive aquaculture that is practiced elsewhere and the management approaches necessary in the old rice fields, which we consider an extensive system.

One of the other aspects of this system, and we suspect you might see a similar thing along the gulf coast, is that we do not really worry about water leaking through the dike, because this whole system can be considered as a floating fluid system. In fact, if any of you have ever tried to drain

Figure 1. Typical impoundment complex of old rice fields on the Santee River, South Carolina

a coastal pond, you already know that. You can drain it only so much, and when the tide comes back the water will come back up on the inside of the levees.

DUCKS

The research we did had a major constraint. The area has historically been managed for ducks. During the years that we were working on the system, we did not do anything to interfere with the duck hunting. I think it is important to point out that duck hunting is, in fact, the management and production of a commercial crop, because many of these places lease their duck blinds, and that is a cash return on that managed acreage.

Water control for vegetation production for ducks is an art-form; it is pond-dependent, and there is a lot of custom and tradition involved which vary from plantation to plantation depending on how the present managers were taught by the previous managers (P. Wilkinson, pers. comm.). Some believe in static systems, while some believe in flow-through systems; they must also deal with the soil types: for example, whether or not they have cat clays will determine their bed-drying period.

The sequence on flooding the ponds for management varies from plantation to plantation. Generally there is a drawdown of the water in the pond to the bed level in late March; the widgeon grass and other vegetation are allowed to germinate for about a 3-week period; and then water is gradually added back. As the water level comes up, the widgeon grass stretches to reach the surface of the water. That process is continued through the summer with the addition of a little rainfall; the local term is that rain "sweetens the water." In the fall, when the ducks begin migration, the water level is gradually dropped. As the ducks come in, they crop the top of the grasses. The managers keep dropping the water levels so that more vegetation is available to the ducks and that, in broadest terms, is the water management process.

Think seriously about ducks; if you are not going to use the DMCA for food production, you can manage them for waterfowl, or wading bird habitat, and that would make a lot of people very happy. In our area, the blinds for duck hunting in old rice fields lease for $1,000 a season. That is a very good return on your acreage.

BLUE CRABS

In the process of "loading the pond," other things come in with the water. One of the first questions that we asked revolved around blue crabs. You can read the lore of South Carolina and find consistent references to the fact that you get "monster" or "giant" blue crabs out of old rice fields. These systems are wild stocked with crabs when the ponds are flooded. That is the part that has stimulated much interest. The important questions are: how many blue crabs are in a pond; can they reproduce; how fast do they grow; do they move around the pond; can you sustain a fishery from the pond? So we attacked these questions. These were several of the assumptions that

we worked with: we did not use supplemental feeding, and we tried to do as much as possible with low fossil fuel support. Of course, we do have a tidal subsidy as we have a 1.5-m tide. You have to understand that when we say "our system," we are talking about Annandale Plantation. We really have to make that clear because there is tremendous variability between these systems.

There are a few things we can tell you about blue crabs (*Callinectes sapidus*) in old rice fields. We have cooperated with Charles Bearden of the South Carolina Wildlife & Marine Resources Department, who gave us a permit to collect sponge female blue crabs from the Santee River. We stocked those in the ponds to see if they would spawn; only once did we see a juvenile blue crab during that experiment and we cannot be sure that it came from the stocking of sponge females. We have never seen natural reproduction in a pond and we have never taken a sponge female blue crab from the ponds. Possibly, the salinity of the brackish water in the ponds is not optimal for crab reproduction.

We were successful in hatching larvae from sponge females in a laboratory situation, and carrying the larvae through to crab stage. It was particularly intriguing because the megalops, which is a difficult stage to carry through larval development, did well if they were held in tanks with widgeon grass. You could observe them climbing up the stalks of the grass, grazing off the epiphytic growth, principally rotifers.

The blue crabs did not grow faster than their wild population (molts/time), but, when they did molt, they increased their size more than their wild cohorts. We did a tag and recapture study for movement and population estimates in the pond. They did not move around and we think that is because there is so much detritus on the bottom that they just sit and stuff themselves. They do not have to work to obtain food. Crab processors liked the crabs because they were fuller and had a higher yield of meat per weight of crab. However, there are serious problems involved in harvesting the crabs. Running a crab-pot operation from a boat in a creek or river is difficult at best, and it is even more difficult in one of these ponds. But, that seems to be the best way to harvest. The impoundments can be crabbed out with sustained effort and they can provide a good source of supplementary income.

We think that it is feasible in the future to do artificial insemination with blue crabs, since this has been accomplished with similar crabs in Japan. With 3-5 years of work, it may be possible to have a hatchery operation for blue crabs. We are not certain that the yield would justify investment in it right now. One of the other possibilities is to use these systems that have blue crabs in them (and obviously blue crabs do very well) as reservoirs for undersized blue crabs that have been taken elsewhere. You could use it as a grow-out operation. However, certain legal constraints would need to be resolved before that could be implemented.

OYSTERS

In addition to the blue crabs, in the tradition of Robert Lunz of Bear's Bluff, S. C. (who did a lot of initial work on coastal impoundments),

we separated 1-year-old sets of oysters (*Crassoatrea virginia*) from intertidal clumps and put them in baskets in a canal in one of these ponds. They grew to marketable palm size and singles in one year, and were of very high quality. This has been very well demonstrated by John Manzie's work in some other coastal impoundments in South Carolina. Although we have not done it, we think there is potential that needs to be investigated for utilization of these systems for clam and scallop culture as well.

CRAWFISH

As part of the process of raising rice, it was conventional to have freshwater reserves behind the impoundments. The levees kept the tidal saltwater out, because rice does not grow in saltwater and the ponds were originally managed with fresh water. It has only been with the maintenance of these systems for waterfowl that they are now managed with brackish water. We have put crawfish (*Procambarus clarkii*) in the old freshwater reserves behind the rice fields and used the Louisiana managemant practices at the appropriate densities; the crawfish have become established. As has been reported, the soil chemistry is critical; the ponds must have the correct clay content for tube-building. We also observed that predation was very heavy on the crawfish and that would be a serious problem. We think crawfish is a species that should be looked at very seriously.

PRAWNS

We did a cooperative experiment with Paul Sandifer of the South Carolina Wildlife and Marine Resources Department on *Marcobrachium resenbergii* in some of these freshwater reserve systems of the rice fields. Once again, we had heavy losses due to predation. There was no supplemental feeding, though, and we did get growth rate that was comparable to ponds with feeding. In this particular system, harvesting of the prawns was very difficult.

FISH

Mullet (*Mugil cephalus*) grow superbly in this system. They grow about one third faster than they do in the wild and there are other fish we have grown as well. Some of you know that, if you try stocking wild shrimp, larval ladyfish (*Elops saurus*) is in the water column at the same time. Ladyfish grow just a little bit faster than the shrimp, and in several years we have raised lots and lots of ladyfish and not so many shrimp. We think the potential is also there for cultivation of bait fish because mosquitofish (*Gambusia* spp.) and mummichogs (*Fundulus heteroclitus*) do very well. The ponds that we have managed for shrimp and fish have very few mosquito larvae in them.

SHRIMP

But the last thing we will mention to you is shrimp, the glamour organism of aquaculture; sexy shrimp. The thought conjures visions of exotic dinners and romantic places, or, at least, full wallets for producers and entrepreneurs. We think it is the aphrodisiac of aquaculture. In the 11 years that we worked at Annandale, the stocking of that system was determined by the water management for the waterfowl and it was all natural stocking. During that period, we had three good shrimp harvests. In other years, we had a harvest of predators or we missed the shrimp postlarvae altogether. When the shrimp were in, they grew very well; there was no evidence of stocking density problems, and we got fast growth. Why is this so? We think the key is the postlarval food supply. We have seen essentially pure cultures of the copepod *Acartia tonsa* develop with densities of 500-100 per ml in May-July. As estuarine ecologists, we ask why this is so. We think that is a particularly interesting question. It could well be that the impoundment is a system that is free of major zooplankton predators, such as Ctenophores, larval fish, and many macrocrustaceans. There is abundant detritus because there are very large amounts of fixed carbon in various stages of decomposition. Harvesting is very difficult because the impoundments have not been constructed for aquaculture purposes. If you are going to do this kind of production effort, you need to design for water control and harvesting.

Parts of this system are being managed this year (1982) for shrimp production. There is a contract with the landowner, and the water management is under the control of the production people. Their proposed procedure is to drain the ponds; rotenone for predators; filter the loading water very carefully (which is done at the time of maximum salinity); let the zooplankton develop; and then stock with about 15,000 postlarvae per acre. The shrimp are showing adequate survival and excellent growth, with no supplemental feed. The growth rate is greater than that in the wild population.

What do we need now? I think we need all the classical questions answered. There are no surprises here. We do not know stocking density, we do not know carrying capacity, we do not know what the disease implications are in these kinds of systems, and we do not have the business infrastructure yet. With the high amount of impoundment acreage that we have available in our area, if we turned everything into shrimp production (and that is a problem when dealing with the large pond impoundment--everything is harvested almost at one time), we simply do not have the processing capability to handle that.

What about a hatchery? What about the use of wildstock? Many major questions remain unanswered.

MANAGEMENT PROBLEMS

Policy Issues

In terms of the DMCA, there are major policy issues in their utilization for aquaculture for the State of South Carolina. In addition to the Corps' concern, policy issues are being addressed by the South Carolina

Coastal Council, and a special study of impoundment processes in South Carolina has begun (this year) with the support of the South Carolina Sea Grant Consortium. The best prospects for a DMCA appear to be a combination of intensive and extensive practices.

Site Variability

Some of these areas could be excellent culture sites for shrimp, fish, crawfish, molluscs, and waterfowl. Certain dredged material containment areas will be feasible for aquaculture, but not all of them. We think it is going to be difficult to assume that we can establish general principles for all impoundments, because of the variability in the abiotic factors, soil type, water chemistry, climate, and tidal amplitude.

Security

Another factor is that security is an extremely serious problem that must be addressed. Our most serious predators have two legs and no feathers. They can do more damage with a cast net in one night than all of the egrets and alligators can do in an entire growing season. That is a serious concern. We guess we would at this point disagree with the speaker this morning when he talked about isolation being to your advantage. We find it is to our advantage to have the system with roads that we can patrol, and there are questions about what could be accomplished in isolated areas.

Infrastructure

It will require an intense personal commitment by the manager to make this system work. We think it should be considered equally as difficult as the management of a dairy farm or a chicken operation. We would emphasize that, when we start talking about aquaculture, we think in terms of production. But there are many other dimensions that must be considered. One which we think we need to give some attention to is the development of an infrastructure to go with the production end. This was emphasized in the discussion of catfish production this morning. It has really only been when the infrastructure of processing, distribution, and marketing has caught up, that production is able to be maximized. You might begin work with the university extension services and Sea Grant advisory services. That is, not all the emphasis should be on production.

Concepts

Finally, we think it is imperative that we understand major conceptual issues that really need to be addressed either before or at least simultaneously with production attempts in these systems. What is the functional relationship of this system with surrounding communities? What ecological processes take place in this system? Are they unique? Are they similar to those which occur in undisturbed wetlands? Are the rate functions for the processes in DMCA the same as in small and large impoundments? Can the principles and technology that have been developed in small, intensive aquaculture systems be scaled up? We are personally pleased to see this conference because it will assist us in addressing these issues.

ACKNOWLEDGEMENTS

Projects like this are only accomplished with the help of many people but particularly Stuart Ballard, Gordon Fritz, and Ken Yetman. Annandale Plantation, where we did this work, is owned and managed by Mr. C. E. Graham Reeves, and he has been very supportive. The work was supported by the South Carolina State Development Board and the Belle W. Baruch Foundation.

REFERENCES

Dean, J. M. 1975. "The potential Use of South Carolina Rice Fields for Aquaculture," USC-BI-75-1, Belle W. Baruch Institute for Marine Biology and Coastal Research, University of South Carolina, Columbia, S.C.

Doar, D. 1936. "Rice and Rice Planting in the South Carolina Low Country," Charleston County Museum, Charleston, S.C.

Miglarese, J., and Sandifer, P. (eds.). 1982. "An Ecological Characterization of South Carolina Wetland Impoundments," South Carolina Wildlife and Marine Resources Dept., Technical Report 51, Charleston, S.C.

Rogers, G. C. 1970. "The History of Georgetown County, South Carolina," University of South Carolina Press, Columbia, S.C.

QUESTIONS AND ANSWERS

Tom Wright (Waterways Experiment Station): In speaking of polyculture, this is the first time that waterfowl has been mentioned. Is there any potential, considering the price of Long Island ducklings, for raising domestic ducks, rather than attracting wild ducks to hunt? That does not require that much management; you would have to supplementally feed them, though. It seems like there might be some potential there.

Dr. Dean: I am really not the best person to answer the question on the Long Island duck operation. I know it is a very intensive culture system and I do not know that you are going to need a containment area to accomplish that. I know we have run-off problems for those systems. Do you have containment areas that you could then utilize this way?

Tom Wright: Yes, containment areas in general seem to have some wild ducks. Why not domestic ducks?

Dr. Dean: Well, because the value of our ducks is much greater by putting someone out at 5:00 a.m. in the morning to freeze their fanny off. We have this masochistic thing that people pay a great deal for. What do you value? If that would work up there, go for it.

Roger Mann: Let me ask a question. Are you are stocking an exotic species of shrimp in your ponds?

Dr. Dean: *Penaeus stylirostris* was stocked in those ponds last year.

Roger Mann: I am interested to know if people who have farms in Texas and stock an exotic shrimp species, if there is a hurricane or some other breach of the dikes, do they have to have the capability to come in and kill all those shrimp so they would not get loose in the natural environment? Do you have similar regulations in the Carolinas?

Dr. Dean: No. Let me explain about *P. stylirostris* in South Carolina. *Panaeus stylrostris* has a lower lethal limit of about 10°C. We routinely see 10° in our water in the winter, so it is just not going to be possible for it to become established in our area. We had the capability at hand for killing the pond, which was a requirement for the grow-out experiment.

Another questioner: How about the gulf coast area?

Dr. Dean: On a personal basis, I am really more in favor of working with indigenous species. But the question was asked if we would cooperate and see if this species would do well in this particular kind of environment. We thought it was a worthwhile question to consider. But in terms of long-term production, I have always been a believer in maximizing an indigenous species.

Same questioner: I am just concerned about the disease problems that may occur in a warmer temperature, year-round--that they could survive here if they were released into the natural environment.

Dr. Dean: I think that is a valid question, but we would have to ask somebody who has that kind of capability to address it, somebody who has interest and a background in bacteriology and virology.

SELECTION CRITERIA AND PROCEDURES FOR ESTABLISHING MARICULTURE FACILITIES IN EXISTING CONTAINMENT SITES

by
Dennis Milligan
Dow Chemical USA
Freeport, Texas 77541

Dennis Milligan

ABSTRACT

Dow Chemical USA carried out a three-phase program of research and demonstration that was sponsored by the U. S. Army Corps of Engineers Dredged Material Research Program between 1973 and 1978. The first phase consisted of chemical analyses of dredged material and 96-hr, auto bioassays which exposed penaeid shrimp to dredged material in seawater. The dredged material was free of significant concentrations of heavy metals, pesticides, and waste metabolites; bioassays indicated that the material was not toxic. The second phase consisted of simulated containment area studies in 1/4-acre ponds. Test ponds were lined with dredged material; control ponds contained no dredged material. This phase concluded that brown shrimp (*P. aztecus*) grew faster and larger in dredged material treatments; treatments required less fertilizer; and no extraordinary mortality was noted in dredged material treated ponds. The third phase was a field demonstration in a 20-acre portion of an actively used containment site. The field demonstration experienced significant problems: ~~(a)~~ overall survival was very low in that mortality from postlarval stage to harvest was ca. 84 percent;
(b) harvesting was a problem due to the irregularities of the bottom of the containment site; and
(c) total control of predators, particularly the sheepshead minnow (*Cyprinodon variegatus*), could not be achieved, even with multiple applications of rotenone. However, shrimp that were harvested passed a wholesomeness test and were marketable. The field demonstration proved technical feasibility of penaeid shrimp culture in a dredged material containment area but failed to determine economic viability.

INTRODUCTION

A great many of you may remember that Dow Chemical had an active mariculture program from 1969 to around 1978. As part of that mariculture program, Dow submitted a proposal to the Corps of Engineers to investigate the feasibility of mariculture in DMCA's (dredged material containment areas). We were awarded the contract in 1975 and began what became a three-phased program of research and demonstration. The first phase was intended to determine the compatibility of penaeid shrimp with dredged material; the second phase was a small-scale simulation of penaeid shrimp culture in experimental ponds containing dredged material; and the third phase, conducted under a separate contract, was the actual demonstration of penaeid shrimp mariculture in an active dredged material containment area.

PHASE 1

For the first phase of research, we obtained dredged material from various sites along the Gulf Intracoastal Waterway between Freeport and Galveston, Texas, throughout the Galveston Bay, and the Houston Ship Channel. At that time the Houston Ship Channel was reported to be among the most polluted bodies of water in the world. Samples of channel sediments were collected (using a 1-cubic-foot Eckman dredge), transported back to our laboratory, and analyzed for pesticides, heavy metals, and waste metabolities. Just to summarize, we did not find any significant concentrations of heavy metals or pesticides, and nothing out of the ordinary among waste metabolities.

The appearance, smell, and texture of dredged material probably varies from location to location. The material we have along the Texas gulf coast looks a lot like grease; it has the texture and consistency of grease, and depending upon where you get it, it smells like grease. This material was placed in 100-gallon tanks, mixed with seawater, and used in static, 96-hr acute bioassays. We used equal numbers of penaeid shrimp of known age and sex from our shrimp hatchery. The bottom line is that we had no toxicity from any of the dredged material, which somewhat surprised us.

PHASE 2

The second phase of our research involved the culture of shrimp in a small-scale simulated containment area. Dredged material was obtained from an active dredge site located between Freeport and Galveston. We leased two barges and barged the dredged material to our barge docks in Freeport, Texas, where they were off loaded and the dredged material was transported to four 0.25-acre ponds. Two of the ponds were lined with the dredged material. By the way, there are concerns over seepage from DMCA's. We had some seepage from our ponds that stopped after the addition of dredged material. The material was spread out, the ponds were filled with seawater containing 30 ppt salinity from our cooling water canals at Freeport, and the ponds were fertilized with commercial fertilizer containing a 5:1 ratio of nitrogen to phosphorus applied at a rate of 5 pounds per acre-foot. Two other ponds

were used as controls. All the ponds were stocked with brown shrimp (*Penaeus aztecus*) from our shrimp hatchery. At the time, Dow operated one of the only two shrimp hatcheries in the State of Texas; the other one was at the National Marine Fisheries Service Laboratory in Galveston.

These are the conclusions from the second phase of our work: surprisingly, the shrimp not only grew faster, they grew larger in the ponds treated with dredged sediments. These ponds produced 150 count shrimp, heads on (150 animals per pound), that were marketable, at least as bait shrimp. We needed less fertilizer in the ponds containing dredged material, probably because of the very high levels of phosphate and ammonia in the dredged material. Lastly, we detected no extraordinary mortality in the dredged material treated ponds and concluded that the material was not toxic to the shrimp in those ponds.

A preliminary economic analysis from our work at that time concluded that, if you could reduce the cost of the ponds--reduce the cost of the feed (e.g. we did not provide supplemental feed)--the largest additional reducible cost would be the hatchery cost. The hatchery operation accounted for over 50 percent of the cost at that time. We said at that time it blocked the economic viability. That was true then, and it is probably also true today.

PHASE 3

The third phase of work was a field demonstration of shrimp culture in an active dredged material containment area. We obtained a list of potential sites from the Galveston District Corps of Engineers. The criteria for site selection were: accessibility by land; existence of a structurally sound levee or dike that would allow you to pond water within the site; proximity to a source of good quality seawater to permit control of pH, salinity, temperature, etc.; and active use and proximity to our laboratory facilities. Dow Chemical has two plants. One is on the old Brazos River; the other is on the new Brazos River. The active site that we chose, DMCA #85, is due south of Freeport, Texas, just off the coast and adjacent to the Gulf Intracoastal Waterway.

Figure 1 shows what the dike looks like during the construction of a DMCA. All the material used for the levee is borrowed from the inside perimeter, so you have a fairly wide and deep ditch along the inside perimeter of the dike. Of course this makes the inside very uneven. This also makes it almost impossible to drain and harvest these ponds.

Durwood Dugger has very adequately covered some of the process for obtaining permits. One of the first things we had to do when we selected this particular containment site was to obtain permission and permits from 18 different sources. This was a research project, so we had a lot easier time obtaining these permits and permissions than I think a commercial operation would. Interestingly enough, the most difficult permits to obtain, and the ones that required the most time to obtain, were those from the Corps of Engineers. But in defense of the Corps, it was only because they had not done it before.

Site #85 was 158 acres in area. This was too large for us to manage. There was not a hatchery in existence that could supply enough postlarval

Figure 1. Newly constructed dike in DMCA #85

shrimp to stock a pond that size. So we constructed a 1000-foot-long internal dike, which created a 20-acre pond area within the larger containment area (Figure 2). Originally, the dredged material entered the containment area at the southwest end. After dewatering, about 3 feet of dredged material remained at this end and about 2 feet remained in the proposed crossdike location. The ponded water along the proposed internal dike's route made it difficult to build the dike. Dike construction was achieved by floating a dragline on a barge and borrowing material from both sides to build up the internal dike.

To control salinity, unwanted algal blooms, and pH, we needed to be able to exchange the water in the 20-acre pond by pumping in fresh seawater. We located a 1,500-gallon-per-minute diesel pump next to the Intracoastal Waterway. One of the first things we learned is that you cannot just put the intake suction pipe out into the canal. Every time a barge came by, it would wash the pipe out on the land. We solved the problem by using screw anchors placed on the bottom of the waterway and laced them to the pipe with rope.

One of the reasons we chose this particular site was that our intake was located 1 mile from the mouth of Brazos River on the Gulf of Mexico. The upper surface of the Intracoastal Waterway had lower density and lower salinity water than the bottom of the canal. Therefore, if evaporation was predominant in the containment area, we could pump the lower salinity water from the upper surface to reduce salinity; if we had heavy rainfalls and dilution became a problem, then we could move our intake toward the bottom of the canal and pump higher salinity water to increase salinity. This reduced the amount of pumping necessary.

We connected the pump to the pond using 10-inch irrigation pipe. This

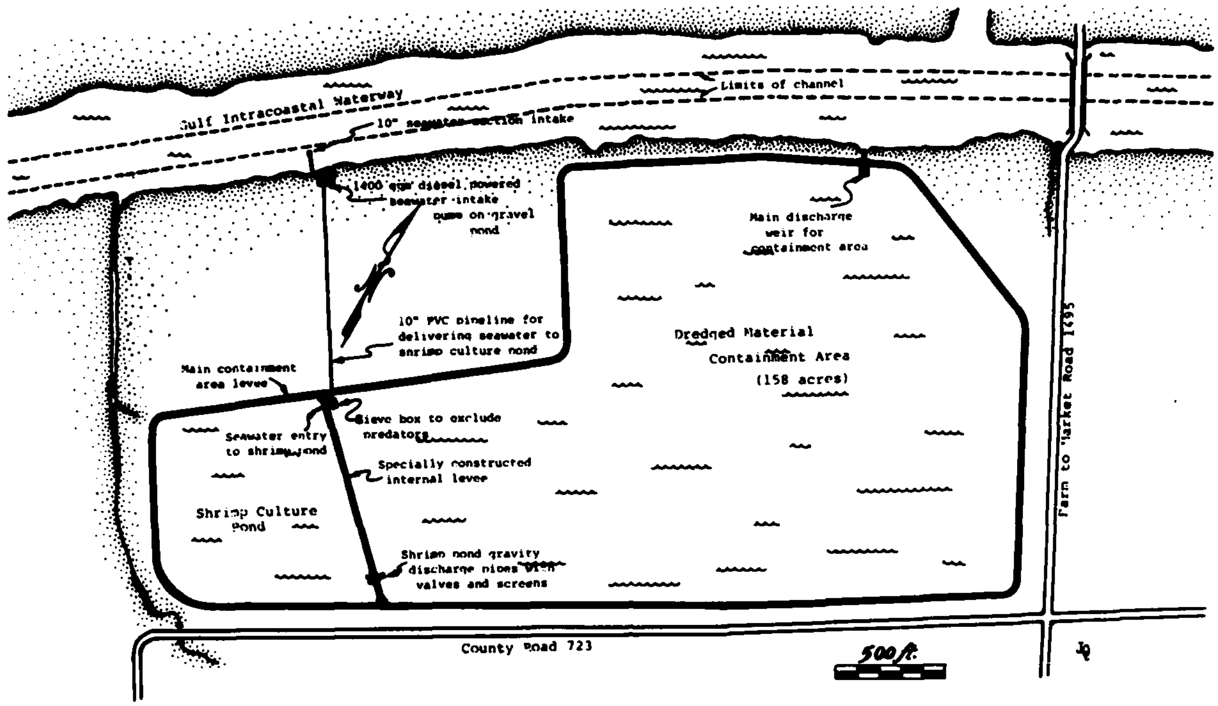


Figure 2. Schematic drawing of DMCA #85, showing placement of crossdike

is very cheap and very easy to use; it is just pressure fitted together. Figure 3 shows the intake and water filtration system. The intake pipe terminates on a self-cleaning screen which we devised. Basically it is a 50-micron stainless steel screen with water flowing across it at a right angle. All the predatory fish, eggs, and larvae are screened out and come out the end. All the screened water falls down into the second box and then down into the third box and then goes over into our pond. We found it to be very effective and trouble-free.

There were complications in the construction of the internal dike that are worth discussing. You may recall, the construction of the main dike around the site left a moat or ditch on the inside. But the moat was not continuous and bridges were left in a couple of places. We built the internal dike across these bridges connecting it to the main dike. The bridged areas of the moat best supported the dike, overcoming problems of depth and poor foundation. Figure 4 shows the proposed route of the internal dike connecting with the main dike across these bridges.

What goes in has to come out. We put in two 24-inch culverts to drain the pond. These were sized to allow a 5-inch-per-hour rainfall to drain from this 20-acre pond. We had a specially fabricated net placed in front of the drains to prevent the escape of the fish.

Before we introduced the postlarval shrimp (PLs) to the pond, we had to kill the predatory fish. There were about 300 pounds per acre of fish biomass in the ponds. A majority of that was silversides (*Mendia* spp.) and sheepshead minnows (*Cyprinodon veriegatus*). We initially treated the pond

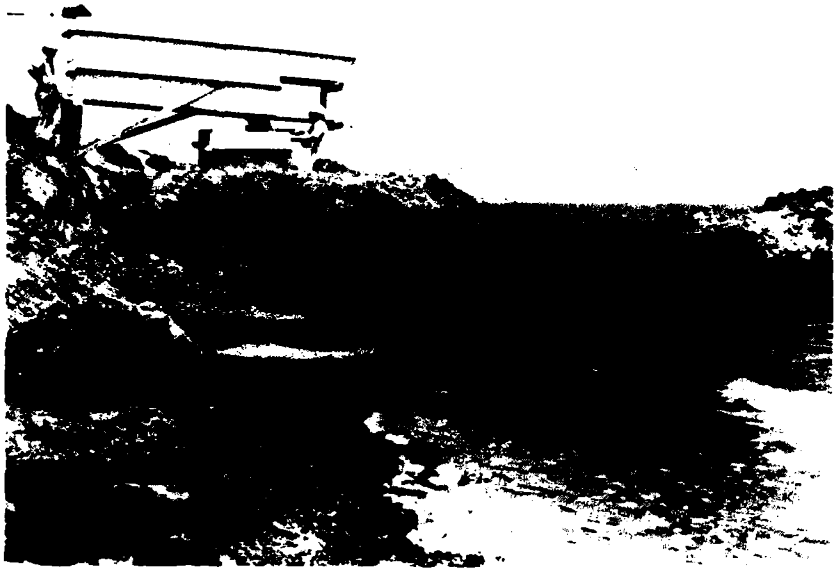


Figure 3. Water intake and filtration system

Figure 4. Proposed route of internal dike. Also shown are portions of the water pumping system and spray aerator

with 0.035 ppm rotonone, applied late at night since ultraviolet light degrades the rotonone. Essentially we killed everything but the sheepshead minnows. Seven days later, rotonone was reapplied at three times the previous rate, a calculated dosage of 0.1 ppm. We still did not eliminate the sheepshead minnow, so we doubled the dosage again. Seven days after the second application, we dosed the pond with rotonone to achieve a concentration of 0.21 ppm rotonone. This reduced the number of sheepshead minnows but failed to eliminate them. At this point the decision was made to ignore the fish that remained in the pond and transfer the shrimp to the grow-out pond.*

We fertilized the grow-out pond, as in phase 2 for the smaller ponds, with commercial fertilizer. We used urea and a super phosphate, applied in a 5:1 nitrogen to phosphorus ratio, at a rate of 5 pounds per acre-foot. This established a good algae bloom in the pond. We only had to make one application, and the algal bloom persisted for the duration of the study.

Like all good projects, our timing was a little off. All of our personnel were committed to the construction of the containment area, so we contracted with Texas A&M University to supply us with PLs from the National Marine Fisheries Service hatchery in Galveston. The shrimp arrived 20 days before we were ready to receive them. We placed the 2,235,000 PLs into a 26-foot-diameter, 13,000-gallon aboveground swimming pool which had been fertilized with 10 pounds of cottonseed meal to promote algal growth (Figure 5).

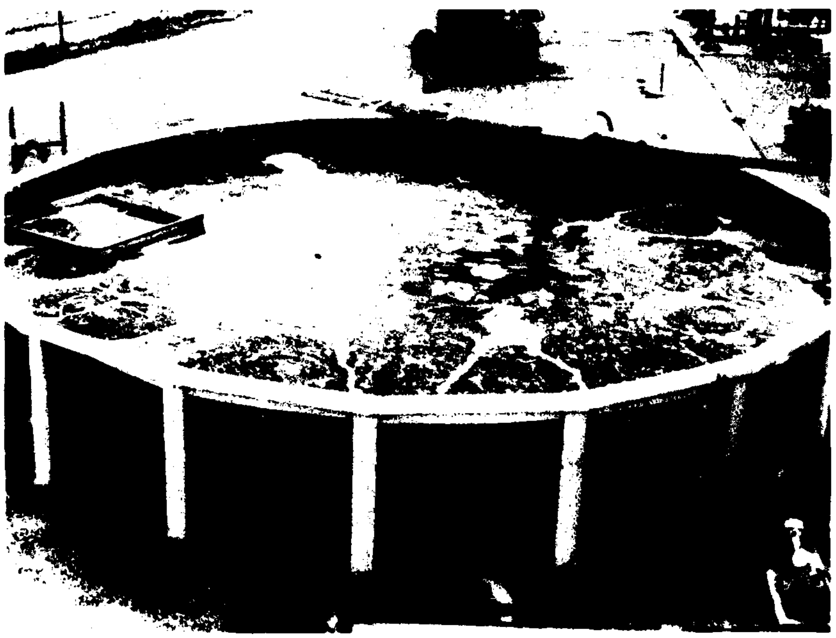


Figure 5. Postlarvae held in swimming pool. Floating brine shrimp hatchery is on the left

* Laboratory assays had indicated that lower concentrations than those used would kill the sheepshead minnows. Our experience indicates that there are factors influencing the effectiveness of rotonone in fish ponds that were not presented in the bioassay tests aquaria.

The PLs were also fed brine shrimp from a floating hatchery within the pool. After 20 days in the holding pool, we recovered only 387,000 one-inch long PLs. The loss of 83% of the original stock was probably due to the severe overcrowding and attendant stress the PLs were subjected to in the makeshift holding pool. The shrimp were transported to the grow-out pond in oxygenated bags placed in plastic trash cans. They were then acclimated to the water in the DMCA. From this point until harvest time, we had about a 90% survival, which gave us an overall survival rate of about 16%.

The biggest problem that we had in the project was in harvesting the shrimp from the DMCA. The bottom of most containment areas is very irregular and they usually have a borrow ditch around the inside perimeter. One of the methods we tried initially for harvesting used a 500-foot seine. This was a 10-foot-deep, 500-foot-long, 0.05-inch mesh net with specially fabricated floats and sink line. We attempted to deploy it (it would cover half the pond) and then pull it to the end, like a purse net. We had very little success with this technique. We found that 90-95% of the shrimp were either going over or under the net. It was virtually impossible to keep the bottom down evenly or to keep the top floating evenly.

The second method we tried for harvesting was the use of a modified otter trawl. This was our most successful harvesting method; however, it was also very labor-intensive. Because of delays in getting our permit, we were not able to initiate this phase of the project until September 1, and 1977 was a particularly cold year with an early winter. Unfortunately, before we could do our final harvest, the shrimp burrowed into the mud and we were not able to completely harvest this pond. However, the growth of the shrimp was measured on a regular basis, and our total harvest, estimated from these assays, would have been at 200 pounds per acre. These were 87 count (heads on) and 143 count (heads off), which are acceptable for bait shrimp. Had we been successful in raising a slightly larger shrimp, and with more efficient harvesting, we would have contracted with Booth fisheries to market the entire crop for use in making fabricated or press-formed shrimp from shrimp pieces. Presently they get most of their shrimp from India, and will accept shrimp as small as 90 count, heads off.

We estimated that we harvested over 1,500 pounds of shrimp from the pond before cold weather set in. These shrimp were submitted to the Department of Commerce for organoleptic testing (which is an appearance, odor, and taste test), chemical analysis, and bacterial counts. As a result of this test we received a certificate of wholesomeness for the shrimp. I have eaten quite a few of these shrimp, and I will attest to the fact that they do not have any off-flavor and you could tell no difference between the wild-caught shrimp and the cultured shrimp from the DMCA.

The major predator on shrimp during the overall project was not birds or fish; it was people. Part of our contract with the Corps of Engineers was to get publicity for the project. The area newspaper ran an article on the project without giving the location, but did show a picture of the pond and surrounding area. People figured out where this place was, and people harvesting shrimp at night became a major problem.

Conclusions were that data from the DMCA demonstration very closely tracked with what we saw from our phase 2 simulated pond. We could get shrimp larger than 100 count, heads on, in 40 days with acceptable survival rates once the shrimp were in the pond. We never found a satisfactory way to

remove the sheepshead minnows from the pond. We never found a satisfactory way of harvesting the pond. We were going to try trapping methods which are used successfully in Asia, but we were not able to test that particular method before the cold weather set in. We determined that DMCA-cultured shrimp will pass the health tests for marketability. We believe we proved the technical feasibility of culturing penaeid shrimp in a DMCA; we do not believe we determined the economic viability. As I said earlier, economic viability will be highly dependent on whether or not there will be a commercial shrimp hatchery established in the United States.

QUESTIONS AND ANSWERS

Charlie Belin (Savannah District): Do you remember what the species of algae was that created the photoplankton bloom?

Mr. Milligan: *Dunaliella* sp. was one of the dominant species. I do not remember the other one, but its in the report. I believe that report's still available.

Norm Rubenstein (EPA, Gulf Breeze Lab): I was just curious as to whether or not you analyzed for any body burdens in these shrimp.

Mr. Milligan: When we submitted the shrimp to the National Marine Fishery Service testing laboratory, that analysis was performed on the shrimp. Extractions were made for pesticides, heavy metals, bacteria, and organolyptic testing.

Norm Rubenstein: Did you see any uptake?

Mr. Milligan: No, they were acceptable for marketing. As a matter of fact, these shrimp were cleaner than those wild-caught.

Jim Andreasen: Where did the spoil come from that you used to line the pond?

Mr. Milligan: It came from the Intracoastal canal south of Freeport, adjacent to the pond. You have one the largest chemical complexes within just a few miles of that particular canal.

Jim Andreason: The material that you got from the Houston Ship Channel, did you have any of those shrimp analyzed for any uptake of any metals?

Mr. Milligan: We did not analyze the shrimp, but we did analyze the sediment. The only heavy metal we detected was strontium. I think it was 1.2 ppm; everything else was less than detectable limits--at that time. Our detectable limits today are much more sensitive than they were then. That was 1975.

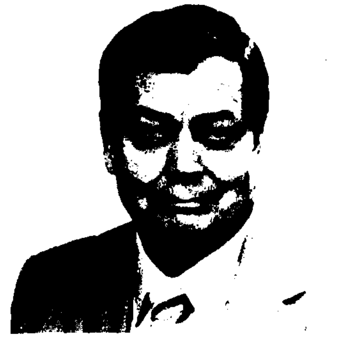
Cornelius Mock (National Marine Fisheries Service): In a recent trip to Brazil, I visited a farm called the Company and Industry of the State of Rio Grande of the North. They are culturing *Penaeus japonicus*. Their grow-out ponds average from about 170-180 acres in size, and they do not drain water from their ponds. They harvest at night, and they will bait one end of the pond with adult *Artemia*. They say they are able to harvest approximately 90% of the shrimp in the pond. I think it is interesting that you can harvest shrimp from a pond without draining the water.

Mr. Milligan: That was one of the things we were going to try before cold weather set in. We simply ran out of time that year. It was the first of November at the end of the project. I agree that it would have been one nice thing to have tried.

AD P002142

DESIGN CRITERIA FOR AQUACULTURE PONDS ON DREDGED MATERIAL

by
Richard E. Highfill
National Agricultural Engineer
United States Department of Agriculture
Soil Conservation Service
Washington, D. C. 20013



Richard E. Highfill

ABSTRACT

The United States Department of Agriculture's Soil Conservation Service (SCS) provides land users with technical assistance in designing and construcing ponds for aquaculture. Several basic design considerations are important for ponds installed on dredged material.

INTRODUCTION

Aquaculture ponds can be constructed at dredged material sites if:

a. Enough water is available for the planned species, considering evaporation, seepage, and the need for water exchange.

b. Water quality is suitable for the planned species or can be made satisfactory.

c. Access to the site is available or can be constructed and maintained.

d. Water released from the site can be treated, if necessary.

e. Storage of water can be provided at the recommended depth and area.

f. Material is available to construct reservoirs and embankments that will be stable for all anticipated conditions.

The pond site must be protected from damage by flooding, sedimentation, and contamination. The soils within the reservoir must be free from residues of pesticides and other harmful chemicals.

Most ponds on dredged material are completely enclosed by an embankment and are filled by pumping. If an embankment pond formed by constructing a dam can be used to intercept and store surface runoff, the criteria outlined are still appropriate, but provisions must be made for principal and emergency spillways adequate to pass flood flows through the reservoir without damage.

Appropriate Federal or State agencies can be contacted for spillway criteria if needed.

EMBANKMENTS

The minimum elevation of the top of a pond embankment should be 1 ft above the water surface in the reservoir when the emergency spillway or overflow pipe is flowing at design depth. The design height of the embankment, however, must be increased to ensure that, after settlement, the actual height will equal or exceed the design height. This increase should not be less than 5 percent, unless detailed soil testing and laboratory analyses indicate that a smaller increase would be adequate.

The design height must also allow for wave action. Recommended allowances are given in Table 1.

Table 1

Wave Height

Maximum Fetch Length* (ft)	Wave Height (ft)
<330	0.5
330-660	1.0
660-1,320	1.5
1,320-5,280	2.0

* Fetch is defined as the longest uninterrupted distance traveled by wind or wave.

If the embankment is for water impoundment only, Table 2 can be used for designing top width. But if the embankment is to be used as a one- or two-lane road for management or nonpublic access, its minimum top width should be 14 and 20 feet, respectively. Additional width, more gentle curves, parking, and surface protection may be needed for public access for fee fishing.

Table 2

Embankment Top Width

Total Height of Embankment (ft)	Top Width
10 or less	6
11-14	8
15-19	10
20-24	12
25-34	14
35 or more	15

The combined upstream and downstream side slopes of the settled embankments should not be less than 5 horizontal to 1 vertical, and no slope should be steeper than 2:1. All slopes must be designed to be stable, even if flatter side slopes are required. This may require foundation or embankment drainage.

SPILLWAYS

Ponds having an embankment around their outer perimeter that excludes outside runoff should have either an emergency spillway with a bottom width of at least 10 feet or have an overflow pipe that can remove the rainfall volume of a 10-year frequency, 24-hour storm. To reduce the hazard of plugging, an 8-inch overflow pipe is the minimum size that should be used.

Rectangular ponds of less than 10 acres should be positioned as nearly as possible with the long axis parallel to direction of prevailing winds. If the pond is more than 10 acres, however, the long axis should be perpendicular to the prevailing wind. This provides for maximum oxygen uptake and the least wave erosion hazard.

WATER SUPPLY AND DEPTH OF RESERVOIR

Wells are the most desirable source of water, but any available source may be used if the quality and quantity are adequate. If water is pumped from rivers and streams or other sources from which undesirable fish may be introduced, filters must be installed on the intake.

The minimum water supply for adequate maintenance is considered to be 15 to 25 gallons per minute per surface acre, measured during the period of lowest flow. Evaporation rates, fish loading densities, and species requirements should be used to establish the rates for given sites. The location of pumps and pipelines should take into account their accessibility for maintenance and repair, protection from overflow and flood hazards, connections to power lines or fuel sources, and future expansion. Aeration of water entering the pond may be necessary to increase dissolved oxygen and dissipate harmful gases. The water can be aerated by a variety of methods such as falling, splashing, or spraying. The water should be discharged into the ponds as far away from the outlet drain as possible, so that "short circuits" are avoided.

The water depths for a few species are shown in Table 3. Catfish and crawfish are highly suited to ponds on dredged material. The values in Table 3 are applicable to warm climates. Additional depth is required in cold climates to prevent or minimize winterkill.

For proper operation, the pond must have facilities for complete as well as partial drainage. Turn-down pipes, quick-release valves, bottom-water release sleeves, or other devices for water level control and pond management should be included in the drain system.

Table 3

Water Depth

Species	Most Desirable Depth (ft)	Minimum Depth (ft)
Channel catfish	4 to 6	2.5*
Crawfish	1.5 to 2	1
Minnows and other bait fish	4 to 6	3
Trout	3 to 5**	3

* Ponds used for cage culture should have a minimum depth of 5 feet where cages are located. (Minimum clearance below the cage is 1 foot but as much as 3 feet is preferred.)

** Ponds supplied by a constant flow of water. If pond is filled only during the rainy season, a depth of 10 to 12 feet is recommended for at least one fourth of the pond's surface.

Antiseep collars should be installed around the pipe conduit in the normal saturation zone if any of the following conditions exits:

a. The settled height of the embankment exceeds 15 feet.

b. The conduit is made of smooth pipe with diameter larger than 8 inches.

c. The conduit is made of corrugated metal pipe with diameter larger than 12 inches.

Antiseep collars and their connections to the pipe must be watertight. The collar material must be compatible with pipe materials. The spacing should be approximately 14 times the minimum projection of the collar measured perpendicular to the pipe. Pipes designed for pressure flow should have adequate antivortex devices. If needed, an appropriate trash guard should be installed at the inlet to prevent clogging of the conduit.

POND BOTTOM

If harvesting will be accomplished by seining, the pond bottom should be smooth and free of stumps, trees, roots, and other debris. Existing channels and depressions in the pond area should be filled and smoothed. The pond bottom should be sloped toward the outlet at a gradient of at least 0.2 foot per 100 feet. For crawfish ponds harvested by trapping, removal of trees, stumps, and other vegetative matter is not necessary unless required by State or local ordinances.

ACCESS AND SAFETY

Provisions must be made for access to the site as well as access to the pond area for operation and maintenance. Ramps should be located as necessary to accommodate aeration and harvest equipment. The maximum grade for equipment access is about 20 percent (5:1 slope). Generally, level areas or restraining barriers are provided for equipment that operates close to the pond edge. Adequate clearance should be provided to protect pumps, motors, fuel tanks, and utility poles from vehicular traffic. Appropriate safety features and devices are to be installed or made available to help prevent people from falling into the pond and to aid them if they do fall in.

SEALING RESERVOIRS

The details of sealing reservoirs are beyond the scope of this paper, but the permeability must be reduced to the point where the losses are tolerable. The materials to be sealed should be thoroughly investigated. This may require laboratory testing. Some of the more common methods use clay blankets; bentonite, a swelling clay; soil dispersant (of doubtful value in dredged material); flexible membranes; cationic emulsion; asphalt-sealed fabric liner; or gleization. Standards, specifications, and procedures are available for all these methods (SCS 1977, 1979).

LANDSCAPE RESOURCES

The developed site should maintain or improve the visual quality of the landscape and should be comparable to adjacent areas. If the site is highly visible to or will be used by the public, appropriate landscaping should be designed.

PROTECTION

A permanent cover of vegetation should be established on all exposed soil surfaces that have been disturbed. If soil or climatic conditions preclude the use of vegetation, other methods may be used for protection. Adequate provisions must be made to protect earth surfaces from wave erosion and turbulent water at pipe inlets and outlets. If needed to protect the embankment face, special measures, such as berms, rock riprap, sand-gravel, soil cement, or special vegetation can be provided.

Fences should be installed if necessary to exclude livestock and unwanted traffic. Roads will need to be surfaced and maintained to prevent vehicles from cutting ruts or sliding into the pond. Dams and levees should be crowned to provide positive drainage.

OPERATION AND MAINTENANCE

A plan for operation and maintenance of the pond should be prepared. This plan should provide for inspection and maintenance of pumps, pipes, valves, spillways, roads, vegetation, and other parts of the system.

Dredged material sites provide an opportunity for use as fish ponds. These ponds can provide fish products for commercial use, opportunities for sport fishing and hunting, and recreation. Proper design, installation, and management are essential to make this use a reality.

REFERENCES

Soil Conservation Service. 1977. "National Handbook of Conservation Practices," Washington, D. C.

Soil Conservation Service. 1979 (rev. ed.). "Engineering Field Manual for Conservation Practices," Washington, D. C.

AQUACULTURE AND DREDGED MATERIAL CONTAINMENT SITES: SIGNIFICANCE OF CONTAMINATED SEDIMENTS

by
Henry E. Tatem
Waterways Experiment Station
P. O. Box 631
Vicksburg, Mississippi 39180

ABSTRACT

Some waterway and harbor sediments dredged by private interests or the Corps of Engineers are placed in shallow dredged material containment areas. These areas are usually constructed adjacent to a waterway or harbor on land that is leased from local individuals or government units. Some are quite large (greater than 1000 acres) and may have a useful life of up to 50 years. Sediments placed in containment areas are fine-grained, highly organic materials that contain plant nutrients such as nitrogen and phosphorus. These sediments also may contain environmental contaminants like metals, pesticides, petroleum hydrocarbons, and polychlorinated biphenyls (PCB). The containment areas are used for sediment deposition every 2 to 5 years and may remain inundated or dry out when not being used.

The biological productivity of many containment areas is low since they are not managed to promote productivity. However, some produce sizable quantities of edible fish and shellfish in their early years and are sought out by the public. Material deposited in containment areas stimulates growth of algae and microorganisms and can be viewed as a nutrient resource. The Corps of Engineers could build containment areas so that they could be used for aquacultural activities which would benefit the local landowner. This type of multiple use should not interfere with the primary purpose.

Whether containment areas are managed to produce bait species or food for human consumption, or allowed to develop naturally, there is concern that contaminants in the sediments could be transferred to animals in harmful quantities. Most contaminants found in dredged material are relatively unavailable to aquatic organisms. However, recent studies, designed to examine

contaminant transfer from sediments, have shown potential uptake problems with respect to certain sediments, animals, and contaminants.

Studies conducted in Texas in 1976 showed that brown shrimp exposed to contaminated dredged material were unharmed and grew larger, in the same time period, than shrimp in control ponds. Later work at a Texas containment area showed that white shrimp could be raised in a containment area with dredged material stimulating algae on which the young shrimp fed. These shrimp were analyzed for contaminants and found to be clean.

This paper discusses results of three laboratory studies where invertebrate animals were exposed to contaminated sediments for periods of 30 to 136 days. Sediments and animals were analyzed for metals and PCB, but not for pesticides or petroleum hydrocarbons. Lead was the only metal which showed a slight potential for transfer from sediment to organism. The data did indicate, however, that PCB in sediment is available. Bioaccumulation of PCB was affected by level of sediment contamination, characteristics of the sediment such as particle size and organic content, and life-style of the organism. Levels of PCB in animal tissue may reach a plateau in a few days or take months depending on the type of PCB in the sediment. Benthic animals or those that feed on sediment accumulated higher PCB levels than water column animals. When exposed animals were placed in clean water without contaminated sediment, they began immediately to depurate the PCB.

Data on sediment and a clam species from a containment area near Port Arthur, Texas, are also presented. The analyses indicated only low levels of contaminants with levels in *Rangia* generally lower than sediment levels.

These data are discussed in relation to use of containment areas for producing edible fish and shellfish or bait species. Excess animals could be used to supplement existing fish or shellfish in nearby lakes or estuaries.

INTRODUCTION

The Corps of Engineers (CE) is responsible for the creation and maintenance of waterways and harbors in the United States. This involves the dredging and disposal of millions of cubic yards of freshwater and marine sediments annually. Prior to 1970, most dredged material was placed alongside waterways or disposed of at convenient aquatic sites. Environmental

legislation and concerns have caused the CE to examine past disposal practices.

The Dredged Material Research Program (DMRP), completed in 1978, studied the significance of chemical contaminants in sediments on organisms and water quality, among other subjects (Saucier et al. 1978). Results indicated that sediment-associated contaminants usually remain associated with sediment particles during dredging and disposal operations and are therefore not toxic to aquatic organisms. Even so, there continues to be emphasis on the placement of dredged material, especially material containing contaminants, in containment areas rather than at open water sites.

Dredged material containment areas are built by the CE on land leased from local landowners. They range in size from less than 100 to greater than 1000 acres and may be used for as long as 50 years. Each containment area is unique, yet all are used by the CE only periodically and can be used by the landowner in the interim as long as the landowner's use does not interfere with the periodic disposal of dredged material.

Productive uses of these areas have been limited, although the feasibility of using marine containment areas for growing shrimp was documented during the DMRP (Quick et al. 1978). Preliminary results showed that small brown shrimp were not killed by exposure to dredged material containing contaminants and, in fact, grew larger than shrimp in control ponds. Work with white shrimp, hatched at a Galveston, Texas, laboratory, showed these animals could be raised in a 20-acre section of a containment area to a marketable size in a few months. The dredged material stimulated algae on which the shrimp fed. Tissue samples sent to a seafood quality laboratory revealed no unacceptable contamination and the shrimp received a Certificate of Wholesomeness.

It is not surprising that some dredged material contains chemical contaminants and it is quite possible that highly contaminated material would not be suitable for use in an aquaculture operation. The majority of chemical contaminants that enter streams, lakes, and estuaries through urban runoff, municipal wastes, plant effluents, etc., eventually are concentrated in bottom sediments. Analyses have revealed metals, pesticides, petroleum hydrocarbons, PCB, and others at concentrations sometimes much higher than background levels. Fine-grained sediments from harbors or waterways near industrial areas are most likely to be contaminated. Many contaminants are tightly bound to sediment particles and are relatively unavailable to aquatic organisms. However, highly contaminated sediments do release low levels of some contaminants to the water column. Certain animals, for example larvae of bivalve molluscs, are extremely sensitive to low levels of metals. Other animals such as deposit-feeding bivalves or polychaete worms actually feed on detritus and organic material associated with sediment particles or process sediments for food. These animals could be expected to accumulate contaminants from sediment.

Organic contaminants such as PCB are likely to be bioaccumulated from sediments although tissue concentrations in most cases are low (Tatem 1982; Rubinstein et al. 1982; Young et al. 1977; Elder et al. 1979; McLeese et al. 1980; McGreer and Reid 1980; McGreer et al. 1981). Some studies have indicated that the metals Pb and possibly Cd in sediments are available to organisms (McGreer et al. 1981; Langerwerf et al. 1982). Selected petroleum hydrocarbons may be accumulated from sediment (Roesijadi et al. 1978; Augenfeld et al. 1982). However, uptake of petroleum hydrocarbons from sediment

has been called minor in comparison to sediment levels (Disalvo et al. 1977) and certainly appears to be less dramatic than accumulation of PCB. These results suggest that serious consideration be given to the potential for contaminant transfer from dredged material to aquaculture organisms if containment areas are to be used for aquacultural purposes. It is possible that animals reared in dredged material containment areas would reveal tissue concentrations of contaminants lower than similar animals obtained from the field.

Aquaculture has been practiced for centuries; however, a number of recent events such as improved culture technology, increasing world population, and industrial pollution of productive coastal areas have resulted in renewed interest. The National Academy of Sciences (NAS) has produced a report on aquaculture (NAS 1978) and the State of Texas has an aquaculture plan (Stickney and Davis 1981). Lovell (1979) has discussed the many benefits of aquaculture and the species being used.

In order to assess the potential of aquaculture in containment areas containing contaminated material, this paper presents data from contaminant research conducted at the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, and discusses the results of other recent experiments. Contaminant analyses of sediments and one animal species from a containment area near Port Arthur, Texas, are also presented. The significance of these results is related to the concept of aquaculture in dredged material containment areas.

MATERIALS AND METHODS

Exposure of Freshwater Animals *Macrobrachium* and *Corbicula*

Two freshwater invertebrates, the prawn, *Macrobrachium rosenbergii*, and the clam, *Corbicula fluminea*, were exposed separately to three concentrations of contaminated sediment in laboratory aquaria. Sediment dilutions were prepared by mixing clean sand with contaminated sediment to produce 0, 10, 50, and 100 percent contaminated sediment. Sixteen all-glass aquaria containing 5 ℓ of substrate and 50 ℓ of water were placed in temperature-controlled water baths. Each aquarium received 50 ml of clean water per minute resulting in over 75 percent replacement of water every 20 hr. Temperatures in the aquaria were approximately 20-22°C, pH ranged from 7.6-8.2, and dissolved oxygen generally was greater than 6.0 ppm. Animals were exposed for 48-50 days and then placed in sediment-free tanks for another 50-80 days.

Contaminated sediment was obtained with a Peterson dredge from the Sheboygan River, Sheboygan, Wisconsin. The collection site was 90 m south of the Pennsylvania Avenue bridge at a depth of less than 3 m. Sediment was collected twice from the same location in 1980. Bremer (1979) has discussed PCB contamination of sediment and fish from this area. Sediment was air shipped to Vicksburg within 36 hr of collection, held at 4°C, and homogenized with a mechanical mixer prior to being placed in the aquaria.

Prawns were purchased from Florida Aquaculture, Inc., in Tampa, Florida, and ranged in size from 5-10 cm. All were from the same batch of postlarvae

obtained from Hawaii. Clams were obtained from a bait dealer south of San Francisco, California, and were air shipped to Vicksburg within 1 day of purchase. Except for some cannibalism among the prawns, there were no problems with the animals during the holding period. Holding conditions were similar to test conditions. During holding and testing, prawns were fed tropical fish food and clams were fed algae.

Tissue samples for both prawns and clams consisted of four to nine individuals taken from each of 16 aquaria on different days during the exposure and depuration periods. Animals were removed from the aquaria and placed in separate tanks containing charcoal-filtered water without sediment for 24 hr before being frozen for tissue analyses. The four to nine individuals were maintained as one tissue sample for each of four replicate aquaria.

Exposure of Marine Animals
Nereis, Mercenaria, and *Palaemonetes*

Rubinstein et al. (1982) exposed three marine organisms, the sandworm, *Nereis virens*; the clam, *Mercenaria mercenaria*; and the grass shrimp, *Palaemonetes pugio*, to four sediments from the New York Harbor area. The work was conducted at the Environmental Protection Agency (EPA) laboratory in Gulf Breeze, Florida, during 1981. Sandworms and clams were purchased from suppliers in Maine and Long Island, respectively, while grass shrimp were collected in northwest Florida. Animals were acclimated to test conditions and water for 4 weeks prior to testing.

Sediments were collected by CE personnel from the New York District and shipped by refrigerated truck to Gulf Breeze. They were stored at 4°C and tested within 2 weeks of acquisition.

The exposure system consisted of three 38-ℓ aquaria per sediment that received 27 ℓ per hour of unfiltered seawater from Santa Rosa Sound. Salinity was 30 ‰ (parts per thousand) and temperature was 22°C. Each aquarium received a 3.5-cm layer of sediment with control aquaria receiving washed beach sand. The three organisms were tested together in one experiment which lasted 100 days. At 6-hr intervals each aquarium received a dose of suspended sediment to simulate sediment resuspension. Tissue samples were taken eight times during the 100-day experiment. Organisms were given a 24-hr purging time before being frozen and sacrificed for chemical analysis.

Exposure of Marine
Animals *Macoma* and *Mytilus*

Two reports, McGreer et al. (1981) and McGreer and Reid (1980), of the same experiment are available, in which sediment bioaccumulation experiments were conducted using two marine bivalves, the clam, *Macoma balthica*, and the mussel, *Mytilus edulis*, exposed to contaminated sediment collected near the Burrard Yarrows ship repair facility. Sediments were collected with a ponar grab, composited, and held in plastic buckets at 4°C until required. Control sediments were obtained from the Fraser River Estuary. These sediments were studied prior to a dredging project because other Vancouver Harbor sediments had been shown to contain high levels of PCB and heavy metals. Test animals were collected from uncontaminated areas in the Fraser River Estuary (*Macoma*) or Howe Sound (*Mytilus*).

Animals were exposed, under static conditions, in 77-ℓ polyethylene containers with 5 ℓ of either test or control sediment placed on the bottom of

each container. Test salinities were 10 and 25 ‰ and temperature was 10°C. Clams and mussels were exposed together using one contaminated and one control sediment at each salinity. Tests were run for 30 days with animals collected from the test containers for tissue analyses at the end of the 30-day period. They were given 48 hr in clean seawater to purge ingested sediments before being frozen for analyses.

RESULTS AND DISCUSSION

Sheboygan Sediment, *Macrobrachium* and *Corbicula*

Data resulting from chemical analyses of the sand, two batches of contaminated sediment, and the test organisms prior to the test are shown in Table 1. The data clearly show the differences between the clean sand and the contaminated sediment. Sand contained lower levels of the nutrients nitrogen and phosphorus and much lower organic carbon, chemical oxygen demand, and total volatile solids. Most metals in the sand were at detectable levels

Table 1

Chemical Analyses of Sand and Sediment Used with the *Macrobrachium* (5-80) and *Corbicula* (11-80)*

Parameter	Sand (N=2)	5-80 (N=3)	11-80 (N=3)
TKN	14.9	3,377	2,963
TP	26.5	1,410	1,123
TOC	123.6	41,767	36,067
COD	94.0	79,367	72,667
TVS%	0.5	9.5	6.2
Cd	0.1	2.8	2.2
Cr	2.6	128.0	44.7
Cu	3.3	145.3	49.0
Fe	1,713.0	18,667	15,300
Pb	2.4	253.0	98.9
Ni	2.5	110.0	23.9
Zn	3.3	290.0	149.3
Hg	<0.1	0.1	0.1
PCB-1242	<0.01	52.3	1.7
PCB-1254	<0.01	8.8	0.8

Species background levels, ppm

	PCB (Wet Weight)		Metals (Dry Weight)			
	1242	1254	Cd	Cr	Ni	Pb
Macrobrachium	0.01	0.01				
Corbicula	0.18	0.31	3.8	12.8	1.3	1.0

* Data are expressed as mg/kg, dry weight, except for TVS. Background levels for the two animals are also shown.

while PCB and HG were below detection limits. The two batches of contaminated sediment were similar except for a few of the metals and PCB. Since the two sediment collections were made at the same location, the large difference in PCB levels was surprising. These data indicate that the 5-80 sediment was more contaminated; however, without specific biological experiments, it would not be possible to state that either 5-80 or 11-80 was more likely to cause toxicity or bioaccumulation.

Prior to the experiment the prawns contained barely detectable levels of the two PCB isomers while the clams revealed higher levels. Clams contained all four metals before being exposed to the contaminated sediment (Table 1). Background animals were taken from the holding tanks at different times from approximately 1 month before testing to the day the test began.

Table 2 shows uptake of PCB-1242 by the freshwater prawns. Bioaccumulation was rapid with organisms reaching apparent plateau levels by day 2. Animals exposed to 50 and 100 percent contaminated sediment accumulated more 1242 than animals exposed to 10 percent. However, there was little difference

Table 2

Tissue Levels of PCB-1242 ± Standard Error for *Macrobrachium* Exposed to Three Concentrations of Sediment 5-80 for 50 Days*

	Treatment PCB-1242, ppm		
Day	Controls	10%	50 and 100%
2	0.07	2.23 ± 0.16	6.50 ± 0.56
7	0.05	2.23 ± 0.20	7.66 ± 0.79
16	0.05	1.80 ± 0.28	6.03 ± 0.69
29	0.06	2.05 ± 0.13	5.18 ± 0.37
40	0.05	2.20 ± 0.04	4.73 ± 0.59
50	0.06	2.15 ± 0.20	4.99 ± 0.84
	Animals Removed from Sediment		
55	0.07	1.80 ± 0.23	5.07 ± 0.88
70	0.06	1.25 ± 0.09	3.63 ± 0.82

* Wet-weight values shown may be converted to dry weight by multiplying by 3.85. Background animals contained 0.01 ppm 1242.

between animals exposed to 50 or 100 percent sediment. Thus, these data have been combined. After 20 days in water without contaminated sediment, animals exposed to 50 and 100 percent sediment decreased from a mean of about 5.8 ppm to 3.6 ppm, a 38 percent decrease. However, they still contained PCB at levels many times higher than controls. To compare tissue levels to sediment levels it is necessary to multiply by 3.85. Thus, a mean PCB level for animals exposed to 50 and 100 percent material would be about 22 ppm (mean level × 3.85) while the 5-80 sediment contained about 52 ppm 1242. Animals exposed to 50 percent sediment were only exposed to about 26 ppm 1242. These data then reveal sediment bioaccumulation factors (BAF) or tissue-sediment ratios of 0.4 or 0.8, very low in comparison to water bioconcentration factors reported in the literature (EPA 1976).

Table 3

Tissue Levels of PCB-1254 ± Standard Error for *Macrobrachium* Exposed to Three Concentrations of Sediment 5-80 for 50 Days*

Day	Treatment PCB-1254, ppm		
	Controls	10%	50 and 100%
2	0.01	0.29 ± 0.05	0.60 ± 0.06
7	0.01	0.52 ± 0.02	1.22 ± 0.10
16	0.02	0.70 ± 0.10	1.59 ± 0.17
29	0.02	0.91 ± 0.11	2.06 ± 0.17
40	0.02	0.99 ± 0.06	2.16 ± 0.22
50	0.02	0.97 ± 0.09	2.24 ± 0.28
	Animals Removed from Sediment		
55	0.03	0.74 ± 0.10	2.25 ± 0.33
70	0.02	0.60 ± 0.06	1.73 ± 0.29

* Wet-weight values shown may be converted to dry weight by multiplying by 3.85. Background animals contained 0.01 ppm 1254.

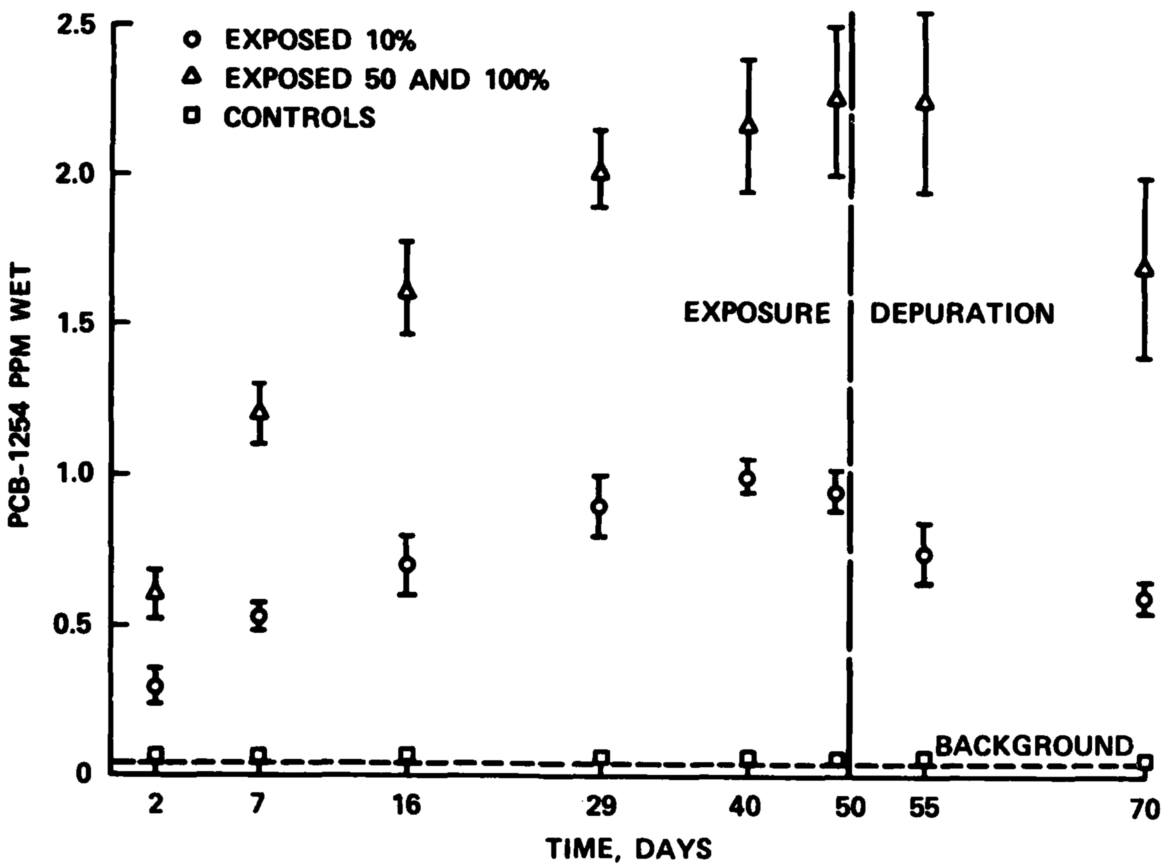


Figure 1. Tissue levels of PCB-1254 in *Macrobrachium* exposed to contaminated sediment for 50 days. Numerical data are shown in Table 3

Table 3 and Figure 1 give data from the same experiment for PCB 1254, a PCB isomer less soluble in water than 1242. Uptake of this isomer proceeded slowly with levels at days 2 and 7 being half the levels after 50 days exposure. The data indicate that at 50 days the bioaccumulation was leveling off. Depuration occurred slowly, with animals exposed to 50 and 100 percent contaminated sediment showing a decline from 2.2 ppm 1254 at day 50 to 1.7 ppm after 20 days in clean water. However, these animals still contained much higher levels of 1254 than controls and it could take months for relatively complete depuration to occur. Comparison to sediment levels shows 8.6 ppm 1254 (dry-weight basis) in animals exposed to the two higher sediment levels for 50 days while the sediment level was 8.8 ppm for 100 percent material.

Thus, tissue-sediment ratios of approximately 1.0 to 2.0 were found. Animals exposed to the 10 percent sediment concentration, where the sediment contained about 0.88 ppm 1254, reveal a sediment BAF of over 4.0. Thus, it appears that animals exposed to sediment containing high levels of PCB 1254 (greater than 10-20 ppm) may not accumulate PCB to those levels while animals exposed to less contaminated material could accumulate the 1254 to levels greater than sediment levels.

Data shown in Table 4 relate to levels of total PCB (1242 and 1254) in clams exposed to contaminated sediment. As with the prawns, these animals

Table 4

Tissue Levels of Total PCB (1242 & 1254) ± Standard Error for *Corbicula* Exposed to Three Concentrations of Sediment 11-80 for 48 Days*

	Treatment Total PCB in ppm			
Day	Controls	10%	50%	100%
3	0.41 ± 0.03	0.80 ± 0.05	0.89 ± 0.06	0.77 ± 0.03
6	0.38 ± 0.04	0.96 ± 0.13	0.72 ± 0.06	0.88 ± 0.02
12	0.33 ± 0.01	0.83 ± 0.02	0.83 ± 0.02	0.70 ± 0.08
24	0.32 ± 0.02	1.11 ± 0.14	1.18 ± 0.07	1.44 ± 0.01
48	0.30 ± 0.01	1.78 ± 0.06	1.25 ± 0.08	2.34 ± 0.19
	Animals Removed from Sediment			
51	0.27 ± 0.01	2.20 ± 0.08	1.50 ± 0.08	2.31 ± 0.19
72	--	1.52 ± 0.19	1.19 ± 0.09	2.29 ± 0.12
96	0.39 ± 0.02	0.86 ± 0.05	0.97 ± 0.08	1.12 ± 0.09
136	0.31 ± 0.01	0.69 ± 0.06	0.85 ± 0.03	0.65 ± 0.01

* Wet-weight values shown may be converted to dry weight by multiplying by 7.42. Background animals contained 0.49 ± 0.03 ppm total PCB.

were shown to accumulate PCB from sediment with differences between controls and exposed animals apparent by day 3. After 48 days animals exposed to 10 percent sediment contained more PCB than animals exposed to 50 percent sediment. Thus, the lower sediment concentration appears to have contained more available PCB. Sediment BAF's (tissue-sediment ratios) for the clams were much higher than for the prawns. The highest possible BAF was for animals

exposed to 100 percent sediment for 48 days. On a dry-weight basis these animals contained over 17 ppm total PCB compared to 2.5 ppm in the sediment. Thus, these freshwater, filter-feeding clams were shown to be more likely to accumulate substantial levels of PCB from sediment compared to the prawns. Background clams revealed relatively high levels of PCB, indicating animals were exposed to PCB in the field. Data for controls show how slowly PCB is eliminated from clam tissues once it is accumulated.

The Table 5 data show Pb accumulation by clams exposed to sediment containing 99 ppm Pb. The Pb data showed a considerable amount of variability

Table 5

Tissue Levels of Pb ± Standard Error for *Corbicula*

Exposed to Sediment 11-80 for 48 Days*

Day	Treatment Pb, ppm: Controls	Treatment Pb, ppm: Exposed-10, 50, 100%
1	0.83 ± 0.37	2.95 ± 0.23
3	1.02 ± 0.25	2.32 ± 0.15
6	1.38 ± 0.38	1.44 ± 0.10
12	0.95 ± 0.02	1.63 ± 0.09
24	1.06 ± 0.19	1.94 ± 0.11
48	1.14 ± 0.05	2.18 ± 0.14
	Animals Removed from Sediment	
51	0.99 ± 0.07	1.53 ± 0.07
60	1.35 ± 0.07	1.61 ± 0.07
96	1.27 ± 0.08	1.31 ± 0.14

* Data shown are dry weight. Exposed animals were removed from the sediment at day 48. Background animals contained 1.02 ppm Pb.

with control levels ranging from 0.83 to 1.38 ppm. Exposed animals at day 1 showed Pb levels higher than animals at day 48. Nonetheless, bioaccumulation from sediment was demonstrated because exposed animals generally contained about twice as much Pb as controls or background animals and animals removed from the sediment began to show lower Pb levels. However, a definite uptake pattern such as that shown for PCB-1254 was not demonstrated. The bioaccumulation was not dramatic since at day 48 exposed animals contained just under twice as much Pb as controls. Levels in exposed animals were around 2.0 ppm, dry weight, compared to sediment levels of 99 ppm Pb, dry weight. Thus, sediment BAF values were very low.

Data on Cd and *Corbicula* are shown in Table 6. Background animals contained high Cd levels and control animals were found to contain as much or more Cd compared to exposed animals. These tissue samples were also analyzed for Cr and Ni with no evidence of bioaccumulation of these metals by clams exposed to sediment 11-80 for 48 days.

In relation to the use of containment areas for aquaculture, these data indicate that some contaminants present in sediments are available to aquatic organisms. Thus, it would be advisable to have analyses conducted on

Table 6

Tissue Levels of Cd ± Standard Error for *Corbicula* Exposed to Sediment 11-80 for 48 Days*

Day	Treatment Cd, ppm: Controls	Treatment Cd, ppm: Exposed 10, 50, 100%
1	2.90 ± 0.20	2.87 ± 0.23
3	2.44 ± 0.11	2.45 ± 0.27
6	2.87 ± 0.34	2.41 ± 0.16
12	3.12 ± 0.42	3.00 ± 0.22
24	3.00 ± 0.18	3.27 ± 0.19
48	2.77 ± 0.19	2.78 ± 0.20
	Animals Removed from Sediment	
51	3.34 ± 0.21	3.66 ± 0.24
60	2.07 ± 0.43	2.26 ± 0.23
96	3.15 ± 0.42	3.27 ± 0.23

* Data shown are dry weight. Exposed animals were removed from the sediment at day 48. Background animals contained 3.83 ppm Cd.

containment area sediments and animals prior to use of the area for aquaculture. Some of these data may be available from the local Corps of Engineers District. Analyses of containment area sediments should be compared to analyses of nearby reference sediments having similar physical characteristics taken from areas unlikely to be contaminated. If levels of contaminants on the priority pollutants list or discussed in EPA publications on toxic substances (EPA 1976) are higher in the dredged material than in reference sediment, this would indicate a need for sediment bioassay/bioaccumulation work to determine if the sediment is toxic or contains contaminants at levels that could be accumulated by the animal proposed for the aquaculture project. Length of the tests could be less than 20 days (Tatem 1982; Rubinstein et al. 1982). If PCB or other toxic organic compound levels are high, tests should be run before animals are added.

New York Harbor Sediment,
Nereis, Mercenaria, and *Palaemonetes*

Chemical analyses of the New York Harbor sediments are shown in Table 7. All four sediments were mainly silt and clay. Very low percentages of sand were found in sediments B and D. The percent organics ranged from over 5 to over 22. The sediment with the highest percent organics was shown to contain the highest levels of PCB, Hg, and Cd. The highest level of PCB, over 7 ppm in sediment C, is not extremely high in relation to other contaminated sediments (Table 1); however, levels of Hg and Cd over 30 mg/kg (ppm) are extremely high. In fact, all four sediments are contaminated with Hg and Cd.

The PCB data from analyses of animals exposed to these sediments are shown in Tables 8-10. In general, all exposed animals were shown to contain higher levels of PCB than controls. Results were most dramatic for the polychaete worm, *Nereis*, an animal that lives in the sediment and feeds on

Table 7

Chemical Analyses of Four New York Harbor Sediments Used by Rubinstein et al. (1982)*

Parameter	Sediment A	B	C	D
% silt	84.6	93.8	88.0	94.3
% clay	15.4	5.8	12.0	5.5
% organics	12.6	5.5	22.3	6.1
PCB	0.46	0.71	7.28	0.72
Hg	4.13	2.85	34.89	2.71
Cd	5.32	11.49	38.60	5.16

Species background levels, ppm, wet weight

	PCB	Hg	Cd
Nereis	0.009	0.375	0.466
Mercenaria	0.016	0.133	0.883
Palaemonetes	ND	0.046	0.123

ND = Nondetectable

* Data are expressed as mg/kg, dry weight, except for silt, clay, and organics which are percentages. Background levels for the three test species are also shown.

Tabl

Tissue Levels of Total PCB in *Nereis* Exposed to Four Contaminated Sediments for 100 Days*

Day	Controls, ppm	Sediment PCB, ppm A	B	C	D
3	0.04	0.03	0.11	0.21	0.13
7	ND	0.09	0.17	0.25	0.16
10	0.01	0.07	0.23	0.21	0.18
17	0.04	0.13	0.29	0.42	0.36
24	0.03	0.17	0.55	0.54	0.30
38	ND	0.17	0.41	0.50	0.54
58	0.03	0.15	0.34	0.51	0.61
100	ND	0.23	0.55	0.44	0.45

ND = Nondetectable

* Wet-weight values are shown. Background animals contained 0.009 ppm PCB. Data are from Rubinstein et al. (1982).

Table 9

Tissue Levels of Total PCB in *Mercenaria* Exposed to Four Contaminated Sediments for 100 Days*

Day	Controls, ppm	Sediment PCB, ppm A	B	C	D
3	0.01	0.01	0.04	0.01	0.06
7	ND	0.01	0.04	0.13	0.03
10	ND	0.02	0.07	0.05	0.06
17	ND	0.02	0.10	0.09	0.08
24	ND	0.02	0.07	0.09	0.05
38	ND	0.03	0.07	0.12	0.06
58	0.03	0.03	0.06	0.06	0.07
100	--	0.02	0.04	0.06	0.05

ND = Nondetectable

* Wet-weight values are shown. Background animals contained 0.016 ppm PCB. Data are from Rubinstein et al. (1982).

Table 10

Tissue Levels of Total PCB in *Palaemonetes* Exposed to Four Contaminated Sediments for 58 Days*

Day	Controls, ppm	Sediment PCB, ppm A	B	C	D
3	ND	0.03	0.05	0.06	0.06
7	ND	0.03	0.09	0.06	0.08
10	--	--	--	--	--
17	0.01	0.04	0.06	0.09	0.10
24	0.05	0.06	0.12	0.10	0.12
38	ND	0.03	0.07	0.07	0.07
58	0.02	0.03	0.06	0.06	0.05

ND = Nondetectable

* Wet-weight values are shown. Background animals contained no detectable PCB. Data are from Rubinstein et al. (1982).

AD-A135 075 DREDGING OPERATIONS TECHNICAL SUPPORT PROGRAM AQUACULTURE IN DREDGED MATE..(U) ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS ENVIR.. 3/3

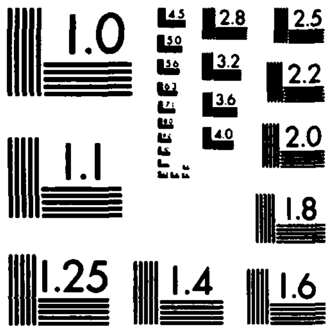
UNCLASSIFIED J HOMZIAK ET AL. OCT 83 WES/MP/D-83-2 F/G 13/2 NL

END

FILMED

1-84

DTIC


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

detritus and sediment particles (Table 8). *Nereis* accumulated the lowest level of PCB from sediment A; however, worms exposed to sediment C, the most contaminated sediment, accumulated no more PCB than worms exposed to sediments B and D. Thus, the level of sediment contamination cannot be used to predict bioaccumulation. Sediment C contained the highest percent organics which probably influenced the availability of the PCB. *Nereis* exposed to sediment C showed a BAF of 0.15 while those exposed to sediments B and D had BAF values greater than 1.0 (Rubinstein et al. 1982).

Nereis is a truly benthic animal whereas the shrimp and clam are in less direct contact with the sediment. The clam is a filter-feeder and is therefore not in immediate contact with sediment. Both of these animals accumulated PCB (Tables 9 and 10); however, the levels were very low. Again animals exposed to sediment C were found to contain similar levels of PCB as those exposed to sediments B and D. Bioaccumulation factors for these two animals were well below 1.0.

Tables 11 and 12 show the results of analyses of grass shrimp tissues for Hg and Cd during exposure to the contaminated sediments. These data are representative of those for the other test organisms. In short, there was no uptake demonstrated. Control values for Hg ranged from 0.02 to about 0.23 ppm with the higher value, found at day 58, greater than values for exposed animals. After 58 days, animals exposed to sediment C showed the lowest levels of Hg. There was no evidence of Cd uptake (Table 12).

Table 11

Tissue Levels of Hg in *Palaemonetes* Exposed to Four Contaminated Sediments for 58 Days*

		Sediment Hg, ppm			
Day	Controls, ppm	A	B	C	D
3	0.05	0.07	0.10	0.15	0.12
7	--	0.03	0.02	0.02	0.04
10	0.08	0.03	0.03	0.04	0.01
17	0.02	0.05	0.14	0.08	0.12
24	--	0.11	0.09	0.13	0.22
38	0.19	0.15	0.10	0.08	0.02
58	0.23	0.08	0.04	0.02	0.13

* Wet-weight values are shown. Background animals contained 0.046 ppm Hg. Data are from Rubinstein et al. (1982).

These data are difficult to relate to use of a containment area for aquaculture since they result from a laboratory experiment where animals were exposed under flow-through conditions which would not simulate containment area conditions. However, they do reveal that PCB in sediment is available to aquatic animals and that infaunal organisms are more likely to bioaccumulate PCB compared to animals having less contact with sediment. It was also shown that the level of sediment contamination cannot be used to predict the eventual level of bioaccumulation and that organics in the sediment influence bioaccumulation. Bioaccumulation can be predicted from relatively short sediment

Table 12

Tissue Levels of CD in *Palaemonetes* Exposed to Four Contaminated Sediments for 58 Days*

Day	Controls, ppm	Sediment Cd, ppm A	B	C	D
3	0.10	0.22	0.32	0.19	0.19
7	--	0.03	0.03	0.03	0.04
10	0.03	0.02	0.04	0.03	0.03
17	0.02	0.01	0.03	0.02	0.04
24	0.02	0.06	0.05	0.06	0.05
38	0.01	0.18	0.06	0.03	0.06
58	0.02	0.06	0.06	0.03	0.05

* Wet-weight values are shown. Background animals contained 0.123 ppm Cd. Data are from Rubinstein et al. (1982).

bioassays since animals exposed for 7 days showed higher PCB levels than controls. There was no indication of bioaccumulation of Cd or Hg, even from heavily contaminated material.

Burrard-Vancouver Sediment, *Macoma* and *Mytilus*

Data from McGreer and Reid (1980) on Vancouver Harbor sediment and the control material used in experiments with two marine bivalves are shown in Table 13. Contaminated sediment contained much higher levels of metals and PCB compared to the control material. Test animals were relatively free of PCB but did reveal high background levels of some of the metals.

Bioaccumulation data are shown in Table 14. Data are from Table 3 of McGreer and Reid (1980). Results of exposure of the animals at two salinities, 10 and 25 ‰, have been combined. After 30 days exposure using static conditions, both species subjected to the contaminated sediment contained PCB at levels greater than controls or background animals. Differences were more dramatic for the deposit-feeding species, *Macoma*. Data for PCB in *Macoma* tissues are wet weight while sediment data are dry weight. A rough estimate would indicate that clams exposed to sediment containing 17.0 ppm PCB accumulated only 3-4 ppm PCB at 30 days. Thus, a sediment BAF of <0.5 is indicated for this animal-sediment combination. Data in Table 14 for *Macoma* demonstrate that Cd, Cu, and Hg levels in exposed animals were below background levels and that As in exposed animals was below control levels. This leaves Pb and Zn with only Pb in exposed animals being substantially higher than both controls and background levels. Data on Zn and *Macoma* reveal some bioaccumulation potential since exposed tissues contained more Zn than controls or background animals. The data also demonstrate that uptake is not directly related to sediment levels. Results for metals and *Mytilus* (Tables 13 and 14) indicate no substantial bioaccumulation for this filter-feeding bivalve. Except for As, tissues from exposed animals were shown to be less contaminated than either controls or background animals. In general, these data show that (1) the deposit-feeder was more likely to accumulate contaminants, mainly PCB

Table 13

Chemical Analyses of Burrard-Vancouver Harbor Sediments Used by McGreer and Reid (1980)*

Parameter	Sediment Control	Sediment Burrard
Cd	<0.2	2.0
Cu	13.0	975.0
Pb	<3.0	215.0
Zn	42.0	2110.0
As	3.0	318.0
Hg	0.05	4.5
PCB-1260	<0.005	17.0

Species background levels, ppm

	PCB (Wet Weight)		Metals (Dry Weight)					
	1254	1260	Cd	Cu	Pb	Zn	As	Hg
Macoma	<0.02	<0.02	0.6	28.3	3.1	262.	6.7	0.4
Mytilus	0.02	--	3.1	35.0	2.6	770.	8.9	0.7

* Data are expressed as mg/kg, dry weight. Background levels for the two test species are also shown.

Table 14

Tissue Levels of PCB and Metals in *Macoma* and *Mytilus* Exposed to Contaminated Sediment for 30 Days*

	Macoma		*Mytilus*	
Parameter	Control	Barrard	Control	Burrard
PCB-1254	<0.02	0.47	0.02	0.08
1260	<0.02	0.12	--	--
Cd	0.32	0.38	5.54	3.78
Cu	17.5	20.7	23.1	31.2
Pb	9.83	16.5	36.1	20.3
Zn	220.0	291.0	874.0	555.0
As	27.3	19.3	7.41	9.45
Hg	0.41	0.44	1.06	0.88

* Metals data are mg/kg, dry weight, while PCB data are mg/kg, wet weight. Animals were exposed at two salinities. These data have been combined. Data are from Table 3 of McGreer and Reid (1980).

and Pb, from sediment; (2) salinity was unimportant; and (3) uptake was not directly related to total sediment levels.

In relation to aquaculture at containment areas, these data simply confirm some of the results of the studies previously discussed. The life-style of the animal is an important factor for determination of the eventual tissue level of contaminant during or after subjection to a contaminated sediment. It would be expected that a bottom-feeding fish would accumulate higher PCB or other toxic organic compound levels than fish that fed on water-column animals. The data do not confirm but do suggest that salinity is not a controlling factor in determining tissue bioaccumulation. This is also shown by the other data showing bioaccumulation by both freshwater and marine organisms.

Sabine-Neches Containment
Area, Sediment and *Rangia*

Sediment and animals were collected with an Ekman dredge from two containment areas near Port Arthur, Texas, in December 1981 (Table 15). These two containment areas are located adjacent to an urban waterway. Even though major oil refining facilities are located close by, the analyses revealed virtually no contamination of sediments or animals with PCB, petroleum hydrocarbons, Hg, or Pb. DDT and other pesticides were at low levels. Cadmium in animals was above sediment levels, but the levels were lower than background levels shown in Tables 1 and 8 for other species. It was expected that sediments and animals from these two containment areas would reveal some contaminants; however, this was not the case. Thus, it is possible that laboratory sediment bioaccumulation experiments overestimate potential bioaccumulation from sediment. Thus, in relation to aquaculture, it may be advisable to conduct a field experiment by placing clean animals at the potential aquaculture site and using later tissue analyses to compare with laboratory results.

Table 15

Analyses of Sediment and Animals (mg/kg) from Existing Dredged Material Containment Areas Along the Sabine-Neches Waterway at Port Arthur, Texas*

Parameter	Site 8	Site 11	*Rangia*
PCB	<0.02-0.03	<0.02-0.03	<0.005-0.01
PAH	<1.0	1.0	--
Hg	0.04	0.05	0.02
Cd	<0.03	0.04	0.26
Pb	10.5	10.5	0.23
Mirex	<0.003	<0.003	<0.001
Toxaphene	<0.08	<0.08	<0.08
Heptachlor	0.001	0.001	<0.001
DDT	<0.004	<0.006	<0.004
Chlordane	0.032	0.024	<0.002

* Samples were collected in December 1981.

Potential for Aqua-
culture in Containment Areas

Virtually no data have been generated concerning potential problems associated with the rearing of aquaculture organisms in areas used to contain contaminated sediments. Though the work by Quick et al. (1978) demonstrated that shrimp would grow in a containment area, they did not emphasize the question of whether contaminants in the dredged material were readily transferred to the animals. Most people would be reluctant to invest in an aquaculture operation in an area where sediments contained contaminants. This would appear to be an unlikely area to begin an aquaculture operation since a successful operation depends on clean water. However, a number of points favor the use of containment areas for aquaculture.

First - the containment areas are already built and in some cases are already producing edible fish and shellfish through natural processes.

Second - all sediments, except possibly clean beach sand, contain detectable levels of some contaminants. Most contaminants are present in sediment particles or are adsorbed to sediment surfaces. Thus, sediments can contain fairly high levels of contaminants while overlying waters, where most aquaculture animals live, are relatively free of contaminants. Sediment particles actually scavenge contaminants from the water column.

Third - data presented here from laboratory research where animals were exposed to highly contaminated sediments showed no toxicity to test organisms and that PCB was the only contaminant consistently accumulated. The work discussed here has also shown that relatively simple laboratory tests are available that can predict potential bioaccumulation problems.

Thus, results of three separate studies, one fresh water and two marine, using a variety of invertebrate species showed that PCB in sediment is available to animals, particularly to infaunal species, but that most metals are relatively unavailable. In the case of PCB, bioaccumulation was influenced by the level of contamination, organic material in the sediment, and life-style of the organism. Animals subjected to sediment containing high levels of PCB generally did not concentrate the contaminant to levels greater than sediment levels. Animals such as shrimp and filter-feeding clams did not accumulate PCB to the same extent as polychaetes or deposit-feeding clams. Animals removed from contaminated sediment began immediately to depurate the PCB; however, complete dupuration would probably take some months. Finally, it should be pointed out that these laboratory experiments were designed to subject animals to highly contaminated material in small aquaria. These conditions could be considered "worst case."

Of the metals considered, only Pb showed the potential for bioaccumulation from sediment. Levels of Pb, however, in the animals were very low in comparison to levels in the sediment. The levels were also low in comparison to PCB levels measured in exposed organisms. Organic contaminants other than PCB were not considered in the three studies discussed here. Some work on accumulation of petroleum hydrocarbons (Roesijadi et al. 1978; Augenfeld et al. 1982) and DDT (Young et al. 1977) has been reported; however, PCB's have received the most attention simply because there seem to be more sediments contaminated with higher levels of PCB than with other organic contaminants. Thus, it seems unlikely at this point that another organic sediment contaminant would be found to be more prevalent and available than PCB.

Many contaminated sediments contain PCB; however, this contamination in many areas is patchy; i.e., the elevated levels are not uniformly distributed in a waterway or harbor. Thus, the dredging process tends to mix sediment from highly contaminated areas with other less contaminated material. .his dilutes the contaminants and would result in lower levels in animals reared in containment areas with contaminated sediments. It would not be difficult, in some areas, to plan a dredging operation such that the most contaminated material was dredged first and would be subsequently covered with cleaner material. This would help isolate contaminated sediment from the water column and from potential aquaculture organisms.

These results indicate that aquaculture in containment areas with contaminated sediments is entirely feasible. Areas or sediments not suitable for production of human food could be used for production of bait species. There are a wide variety of animals, such as fish, shrimp, and bivalves, that can be cultured. Many of these animals can be raised in low salinity environments as well as freshwater areas. Demonstration projects as well as dependable sources of young animals for stocking are badly needed. It would be advisable to attempt to rear different organisms together in a portion of a containment area where a known contaminated sediment had been placed to determine whether the laboratory results discussed herein were reproduced in the field. Obvious areas for demonstration projects range from South Carolina to south Texas, especially areas where aquaculture research is already under way and containment areas are located nearby.

CONCLUSIONS

The following conclusions can be drawn:

a. Chemical analyses of sediment and animal tissues from laboratory experiments have shown that some contaminants are potentially available to aquaculture organisms.

b. Bioaccumulation, however, is influenced by sediment concentration, organism life-style, and length of exposure. Since numerous aquaculture species with various life-styles are available, it would appear that most containment areas could be used for aquaculture without major problems.

c. Simple laboratory tests are available to predict bioaccumulation. The CE has previous experience in taking sediment and tissue samples from existing containment areas for chemical analyses to identify potential problems.

ACKNOWLEDGEMENTS

The author greatly appreciates review of this manuscript by R. Peddicord, J. Lunz, and J. Homziak, all of WES, and acknowledges experimental work of N. Rubinstein (USEPA) and E. McGreer (EVS Consultants Ltd). Skilled technical assistance for experiments conducted at WES was provided by S. Portzer.

LITERATURE CITED

Augenfield, J. M., Anderson, J. W., Riley, R. G., and Thomas, B. L. 1982. "The Fate of Polyaromatic Hydrocarbons in an Intertidal Sediment Exposure System: Bioavailability to *Macoma inquinata* and *Abarenicola pacifica*," Marine Environmental Research, Vol 7, pp 31-50.

Bremer, K. E. 1979. "PCB Contamination of the Sheboygan River, Indiana Harbor and Saginaw River and Bay," Proceedings of Fourth US-Japan Experts Meeting - Management of Bottom Sediments Containing Toxic Substances, October 1978, Tokyo, EPA 600/3-79-102, pp 261-287.

Disalvo, L. H., Guard, H. E., Hirsch, N. D., and Ng, J. 1977. "Assessment and Significance of Sediment-Associated Oil and Grease in Aquatic Environments," Technical Report D-77-26, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Elder, D., Fowler, S., and Polikarpov, G. 1979. "Remobilization of Sediment-Associated PCB by the Worm *Nereis diversicolor*," Bull. Environ. Contam. Toxicol., Vol 21, pp 448-452.

Environmental Protection Agency. 1976. "Quality Criteria for Water," Washington, D.C.

Langerwerf, J. S. A., deKock, W., Marquenie, J. M., König, J. W., and Houpt, P. M. 1982. "Bioavailability of Pollutants in Sediments," Unpublished manuscript presented in New Orleans, 13-17 September 1982, at the US-Dutch Meeting on Memorandum of Understanding of Dredging Technology, Proceedings to be published by USAE Waterways Experiment Station; Authors address - TNO, P.O. Box 217, 2600 AE DELFT, The Netherlands.

Lovell, R. T. 1979. "Fish Culture in the United States," Science, Vol 206, pp 1368-1372.

McGreer, E. R., and Reid, B. 1980. "Contaminant Mobilization and Bioaccumulation from Marine Sediments Adjacent to a Ship Repair Facility," Project 474 by EVS Consultants Ltd., North Vancouver, B.C., for Environment Canada.

McGreer, E. R., Reid, B. J., and Nelson, H. 1981. "Mobilization, Bioaccumulation, and Sublethal Effects of Contaminants from Marine Sediments," Can. Tech. Rep. Fish. Aquat. Sci. 990:130-151.

McLeese, D. W., Metcalfe, C., and Pezzack, D. 1980. "Uptake of PCB From Sediment by *Nereis virens* and *Crangon septemspinosa*," Arch. Environm. Contam. Toxicol. Vol 9, pp 507-518.

National Academy of Sciences. 1978. Aquaculture in the United States Contraints and Opportunities, NAS, Washington, D.C.

Quick, J. A., Milligan, D. J., Hill, S. E., Hover, R. J., and McIlhenny, W. F. 1978. "Field Demonstration of Shrimp Mariculture Feasibility in Dredged Material Containment Areas," Technical Report D-78-53, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Roesijadi, G., Anderson, J. W., and Blaylock, J. W. 1978. "Uptake of Hydrocarbons from Marine Sediments Contaminated with Prudhoe Bay Crude Oil: Influence of Feeding Type of Test Species and Availability of Polycyclic Aromatic Hydrocarbons," J. Fish. Res. Board Can., Vol 35 pp 608-614.

Rubinstein, N. I., Lores, E., and Gregory. N. R. 1982. "Accumulation of PCB, Mercury, and Cadmium by *Nereis virens*, *Mercenaria mercenaria*, and *Palaemonetes pugio* from Contaminated Harbor Sediments," submitted to Aquatic Toxicology.

Saucier, R. T., Calhoun, C. C., Engler, R. M., Patin, T. R., and Smith, H. 1978. "Executive Overview and Detailed Summary," Technical Report DS-78-22, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Stickney, R. R., and Davis, J. T. 1981. "Aquaculture in Texas, A Status Report and Development Plan," TAMU-S6-81-119, College Station, Tex.

Tatem, H. E. 1982. "Bioaccumulation of PCB by Freshwater Prawns and Clams Exposed to Contaminated Dredged Material," Engineering and Scientific Research at WES, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Young, D. R., McDermott-Ehrlich, D., and Hessen, T. 1977. "Sediments as Sources of DDT and PCB," Mar. Poll. Bull, Vol 8, pp 254-258.

LEGAL ENVIRONMENT OF A CONTAINMENT SITE: LAWS GOVERNING THE ACQUISITION, MAINTENANCE, AND OPERATION OF DREDGED MATERIAL DISPOSAL SITES

by
Rick Harrison
U. S. Army Engineer District, Galveston
Galveston, Texas 77553

Rick Harrison

ABSTRACT

Prospective aquaculturists should be aware of the legal instruments governing the ownership and use of containment areas. The Corps of Engineers (CE) does not usually own disposal property, it only holds the easement to dispose of dredged material on the property. State real estate law governs the rights and and relationships pertaining to the property. Disposal easements grant the holder (the CE) all necessary and incidental rights to enjoy the easement, including construction and maintenance of levees, water control structures, etc. These do not have to be specifically identified in the easement instrument. The owner reserves all other rights. Activities by the owner or any leasor may not interfere with the easement holder in enjoying his easement rights, i.e. they may not interfere with the CE's disposal activities. Clearly, as a first step, the leasor or prospective culturist must deal with both the owner, to lease the right to use the property for aquaculture, and with the CE, to obtain a "consent document" for this activity. Only with these two agreements in hand can any other activity proceed.

I am a real estate attorney for the Corps of Engineers. Our jurisdiction covers the whole Texas coast, about 100 miles inland. So we have all sorts of real estate problems with easements and fee owners and easement holders. As you know, we are one of the largest disposal leasing holders in the country. My comments today are going to be limited to disposal easements, containment sites that are controlled by the Corps of Engineers. I

do not mean that they are owned by the Corps, but the easement rights are owned by the Corps of Engineers.

I want to make a general comment as to what laws apply to government disposal sites. Even though they are Federal Government disposal sites, the state real estate law (of whatever state they are contained in) does apply with respect to the rights of the parties involved, whether you are the owner or a potential lessee as a mariculturist, or whether you are someone who holds a lease on the land for grazing or some other purpose. The rights are determined by the state, case law, and such.

Generally speaking, the United States gets involved in this area through local cooperation projects. In other words, we do not buy these rights directly from the landowners. The local sponsors, such as the navigation district or local flood control district, will buy an easement right; they might even buy a fee from the landowner. They then assign or convey to the United States the right to dispose of dredged material on a piece of property, in which case we generally build the levees, etc. Up to now, the traditional idea has been that a disposal easement is perhaps the most burdensome surface easement that you can have on your property. On most of these easements, the landowner reserves all of the rights that are not inconsistent with the easement rights that he is granted. In other words, he retains the right to use the property also, just as the government does, to, for example, put dredged material in it. The highest and best use of the reversion to the landowner has been hunting leases.

For a leveed tract of land inundated about every three years, there are not very many rights left to the landowner, with the exception of duck leases, hunting leases, and grazing if there is a sufficient period of time for the property to dry out between disposal events. From that standpoint, by using mariculture, the landowner could someday make an economically beneficial use out of his property, even though burdened by disposal easements.

The basic law in Texas is that if you, a landowner, convey an easement (regardless of whether it is to the United States or to anyone else) to deposit and contain dredged material, that would include the right of the easement holder to build levees and keep them maintained, and it would prevent the landowner from degrading those levees. You as a mariculturist would want to know that. It is important to know who you are dealing with, who owns the land, and then who owns the easement to dump dredged material. You want always to look at the easement if you are going to lease a containment area, go on the property to do research, or anything; you want to know what rights lie with whom.

You also need to read the reservation clause which specifies what the landowner reserves for himself. At times he will reserve uses that may not be stated in another instrument. The landowner has the right, for instance, to come in and also dump dredged material in a disposal site. He would also have the right to raise shrimp in his disposal site, if he could do so without substantially interfering with the easement rights that he (or his predecessor) granted to the government. The reservation clause does not permit an owner to come in and degrade the levees for his purposes and then expect the government to rebuild the levees every time they need to use the area.

Up to now, grazing and hunting leases have been the only recognized uses of these disposal areas other than dredged material disposal. One

reason for this very limited use is that permanent structures are not allowed in areas that are to be used for disposal used every 3-4 years. Federal case law holds that, if the government has an active need for the area and they have an easement right, they have the right to prohibit permanent structures. Permanent structures often necessary for successful mariculture would probably be taboo in an area for which the government could show an active need.

Many people too often call them "government disposal areas," and they are really not; they are "government easement for disposal" and it is someone else's land. Mariculturists, wanting to lease a disposal area, and knowing that it is a Corps of Engineers disposal area, may think to approach the Corps for a permit to use the area. Often they do not even need a permit from the Corps if it is not required under certain Section 10 or 404 provisions, such as clean water acts. But the United States, just because we hold the easements, has no right to grant the real estate permission for a mariculturist to go on there and raise shrimp. You first have to make your peace with the landowner. This is a little different when the Federal Government owns an area. We have two of them locally, Pelican Island and Fort San Jacinto. These are government fee-owned tracts, and you would make arrangements with the United States if you ever wanted to use them for mariculture.

If you were approaching us for a required permit, the Corps would perhaps issue the necessary permit, but it would convey no real estate rights; you would have to go to the landowner and get his consent. If you went to the landowner and he consented, then you could surely use the area for raising shrimp during periods of off-dredging. Then you would very likely, to protect yourself and to prevent any problem, want to come to the Corps of Engineers and get what we call a "consent document" by which the Corps will consent to your use of this area. Because we have a vested interest in the levees and in 4 years we are going to be coming back in with dredged pipe and you have to do something with your shrimp that year, you must have the Corps' consent. I believe the two interests could probably work together.

Before you can enter an area and use it for mariculture you do need to read the easements very carefully and determine what the rights are of all the parties involved and who owns the right to dispose material. Then you would be responsible for making arrangements with all involved parties. The last speaker commented on the expense of setting up mariculture facilities and I am certain it would be very expensive for a private owner to develop his own mariculture facility. That is where the benefit of using dredged material containment areas may come in--to use areas that already have levees. Levees account for a significant portion of the capital expense of a mariculture operation.

There is also a question concerning the ownership of the materials within a containment site. When the government simply has an easement to place dredged material on someone's land, it does not own that material. If mariculturists need to use that material for the construction of interior dikes or other purposes, they have to obtain that right from the landowner. The government would have certain rights to protect and maintain existing levees and, in some cases, areas have been specifically set aside to provide borrow material for the levees, but these rights should be set out in the easement instrument. The genreal rule is that the landowner owns whatever material we put on his land. If you get a lease from him to raise shrimp or

whatever, you can move it around any way that you wish as long as the levees are not degraded and the Corps' use of the containment area is not impaired.

The courts in Texas and most other states balance the interests of all parties. If one party holds an easement on the property to deposit dredged material and an owner contests those rights, they will consider who is being the most reasonable. If you are the owner granting the easement, you have to grant that easement holder all the necessary and incidential rights he needs to enjoy the easement he has obtained, such as building levees, even though the easement may not specifically say that. However, if you are the easement holder in Texas, you have a duty to exercise your easement rights in a reasonable and prudent manner so you do not burden the surface any more than necessary. This is where the United States may be particularly vulnerable in easement cases. The United States does not have to show that they need the property and that they do have a reasonably foreseeable use for the land to keep you, as a potential mariculturist, from using the property. However, they would not have a desire to do this unless mariculture is going to inhibit the use of the tract as a disposal area.

There is one other party that you have to consider if you are going in to develop any sort of permanent or long-term mariculture operation, in Texas especially. That is the mineral owner. We do not deal with the mineral owner very often. Conflicts occur occasionally over issues such as whether a mineral developer has to raise his facility above our dredged material levels or whether the Corps can put dredged material in on top of his wellhead. As most of you probably know, the mineral estate is dominant in Texas. If the party which owns the property does not own the minerals, the mineral owner has the right to come in and develop in order to extract the minerals, as long as he does so in a reasonable and prudent manner, so that he does not burden the surface any more than necessary.

I do not really know whether this audience is predominantly mariculturists or scientific researchers. But as owners or leasers of dredged material containment area property, this use has a potential of being fairly lucrative from the economic standpoint, at least more so than letting the land sit idle or leasing it for grazing or some such use. The Corps of Engineers is looking for possible joint beneficial use of containment areas by the landowner and the government. The waterways need to stay open, of course; we need to have some disposal sites, even for contaminated material. If there is a use that can be made to promote more revenue for the landowner, be environmentally sound, and not interfere with the Corps' mission, I think there is no real legal problem. You just have to make sure you are dealing with all the right parties and understand the instruments of agreement between them.

QUESTIONS AND ANSWERS

John Null, Jr. (PISCES): When pumping saltwater for a saltwater mariculture, who gives the permit? In other words, to go out here and set a 24-in. pump in the middle of Galveston Bay and pump it into a levee. Who has the final approval?

Mr. Harrison: That is outside of my realm, but I would imagine that the agency in Washington that is the counterpart of the state water quality board would be responsible. Well, if it is in the Bay it probably would be the State of Texas. The state, as you know, owns all the Bay bottom unless it has been patented. As far as the water goes, from an environmental standpoint, I cannot tell you what agency would be in charge. You are talking about pumping it into an inland disposal site?

John Null: Yes, for example, in a study one of the individuals did here at Port Arthur, checking on some shrimp that were put into a containment pond when the shrimp were migrating into the Bay, they turned the pumps on and sucked the wild shrimp up into the lake and then cut it off, and then harvested that shrimp. The article read that he used about 8 gallons of gasoline to raise some (I forget how many) thousands of pounds of shrimp, and it cost him nothing. My concern is, all up and down the coast, from this angle, if the pumps are put out there, you see pictures which indicate that you had to have the water to go in. You are going to raise shrimp. If you raise them on the coast, you are going to have to raise them while the postlarvae shrimp are coming in from the Gulf of Mexico, which is from May to October. You are going to suck those postlarvae shrimp into those pumps unless it is protected in some way. This is my concern. I am in the commercial industry, and I came to this meeting specifically for that purpose.

Mr. Harrison: Maybe someone else would have an idea.

Mr. John Lunz (Waterways Experiment Station): I am glad that question was brought up, but I do not know if there is an answer. The issue of using natural recruits is one that we surely have considered. We hope that, if we cannot get an answer to it today, it is something that the legal subgroup will bring up tomorrow and at least reach a tentative conclusion about.

Bart Thebarge (Virginia Institute of Marine Science): It was mentioned earlier that much of what the Corps does in this area is done under authority to protect navigation. I wonder if you see any limitations for the Corps in modifying its operations in the disposal activity to promote or aid aquaculture? In other words, could the Corps work more closely with someone who is interested in aquaculture and perhaps modify their procedures in a way that would facilitate the development of aquaculture?

Mr. Harrison: I would hope that is the purpose of this conference. As I understand it, this is put on by the Department of the Army to make alternate uses for these disposal areas a little more viable. We have a selling job, also, to be quite frank. If the Corps of Engineers, mariculturists, and landowners can use the disposal site together and make more economical use of it through mariculture (catfish or whatever), yes, I think that the Corps would be supportive because it would significantly reduce the cost, if not to the Federal Government directly, then to the local sponsors who are responsible for providing real estate. If the landowners can be convinced that there is some profitable use that can be made of the area after the levees are constructed, it would significantly reduce the cost of the real estate to the local sponsors or the person who is responsible for buying real estate on the property.

Bart Thebarge: So you would see that type of activity directly in line with the navigation aspect?

Mr. Harrison: Yes, the navigation aspect of it, of course, is the primary reason for the containment areas, but many of our projects have many ancillary aspects (i.e., recreation). I do not see any reason why aquaculture would not be just as valid as a recreational purpose.

FRESHWATER TARGET SPECIES SELECTION AND MANAGEMENT

Summary Comments of Dr. Robert Romaire, Moderator

We covered various topics regarding target species selection and management of freshwater organisms, looking at such topics as stock procurement, technique, special pond design, harvest considerations, water quality criteria, disease and growth problems, market outlook, and suitable polyculture candidates.

In terms of target species, there is no lack of potential freshwater candidates for use in aquaculture operations in dredged material containment sites. We discussed channel catfish, crawfish, bait minnows, and trout, which are very large, commercially viable aquaculture systems within the country today. Approximately 70,000 acres of commercial catfish ponds are in production in this country; approximately 85,000 to 90,000 acres are in commercial crawfish production; and thousands of acres are in bait minnows. There is some small acreage for the freshwater prawn. Waterfowl were also discussed and we believed that it was a very intriguing area to explore.

Regarding stock procurement and techniques, frankly there is no problem in that area with the freshwater species. We have some very large commercial industries in this area, so stock procurement is not a very difficult problem. The animals, indeed, are available. Our freshwater organisms undergo what we call direct development; they hatch from the egg into a miniature organism. There is no complex early-life history as with many marine species. In summary, the animals are there, available for potential use in these systems.

Regarding special design and harvest considerations, we believe that each site, obviously, would have to be considered individually. It is conceivable that there may be some potential for using existing upland areas for use in crawfish culture that might not require a great deal of modification in pond construction or otherwise. Crawfish are harvested in this country with baited wire traps, so one does not need to have a pond specially modified or constructed to accommodate seining operations and so forth.

A very important consideration with other organisms such as catfish is that after you put the animal in you have to be able to get him out. Perhaps in conjunction in working with the Corps and so forth, cells or whole containment sites could be modified or constructed to facilitate the harvest process, particularly with finfish species.

QUESTIONS AND ANSWERS

Question: You mentioned the availability of stocking animals, but what about *Macrobrachium*?

Dr. Romaire: That is a special case that I did not elaborate on. There was a stock procurement problem. The people who have done the work, Paul Sandifer and others, believe that its time has come. They have shown that it can be grown successfully and it is being done. It is a commercially viable industry of small size, though, in Hawaii, South Carolina, and Texas. They

are waiting for the hatcheries and for the investors who are going to invest the large amount of money required to develop hatchery operations to supply the seed stock. There are no major problems there; it is simply the hatchery phase which is a big kink in the system. With increased demand for seed stock, as may result from the success of containment area culture of these animals, development of hatcheries with speed up.

Jeorge Leong (National Marine Fisheries Service): You mentioned that the incidence disease may be similar to other commercial operations, but, contaminants aside, is it possible that disease might go up?

Dr. Romaire: That is possible. There are a lot of things that we can speculate on. To my knowledge, we simply have done no work at this scale. We have cultured these animals in containment sites and we believe that we could therefore go directly into pilot studies, where we will learn to solve the problems.

SALTWATER TARGET SPECIES SELECTION AND MANAGEMENT*

Note: The recording of the marine species selection discussion was not available for transcription. Other species, aside from penaeid shrimp, bait minnows, and waterfowl, were discussed and proposed for inclusions as recommended species. Contacted discussion group members, workshop attendees, and marine aquaculture authorities suggested the list include the following species for commercial prestocking culture:

1. Redfish (*Sciaenops osceZlatus*): Dr. Robert Stickney, Texas A&M University; Mr. Walter Tatum, Claude Peteet Mariculture Center; Mr. Durwood Dugger, Commercial Shrimp Culture International; Mr. Gene McCarthy, Texas Parks and Wildlife.

2. Striped bass (*Morone saxatilis*) and its hybrids: Dr. William Lewis, President, American Fisheries Society; Dr. Paul Sandifer, South Carolina Marine Resources Research Institute; Mr. Vernon Minton, Claude Peteet Mariculture Center; Mr. Reggie Harold, Dennis Wildlife; Dr. John Krenter, Baltimore Gas and Electric Company.

3. Trout (*Salmo gairdneri*): Mr. Walter Tatum and Mr. Vernon Minton, Claude Peteet Mariculture Center.

4. Oysters (*Crassostrea* sp., *Ostrea* sp.): Dr. George Krantz, Maryland Cooperative Shellfish Research Laboratory; Dr. John Dean, University of South Carolina; Mr. Durwood Dugger, Commercial Shrimp Culture International.

5. Penaeid shrimp: Penaeid shrimp hatchery facilities are indeed limited as the demand has not been sufficient to induce large investments in this area. Conversations between J. Homziak and J. Lunz (editors of this proceedings) and Dr. Addison Lawrence (Texas A&M University), Mr. Durwood Dugger (Commercial Shrimp Culture International), Dr. Jack Parker (Laguna Madre Shrimp Farms), and Dr. Paul Sandifer (South Carolina Marine Resources Research Center) support the contention that adequate seed stock is available

---

* Moderated by Dr. David Aldrich.

at present for pilot-scale operations. With guaranteed demand and adequate notice, significantly greater quantities of post-larval shrimp could be reliably supplied.

The question arose about the potential for cage culture of finfish. It was pointed out that one could probably count the number of successful commercial finfish cage operations in this country on one hand, which is some indication that it is a difficult type of culture.

The use of these impoundments for recreational and/or fee fishing received some attention and could have very important implications. This use, too, is site-specific, depending upon the area's proximity to metropolitan areas and whether or not the containment site is on privately owned land, publicly owned land, or otherwise.

Regarding water quality criteria, obviously the water quality within these impounded sites would have to be within ranges conducive to fish production to be considered. Again we look at each site on an individual basis. There were some questions regarding fish production in these systems, specifically off-flavor of the fish, which is often related to the intensity of culture, algae blooms, and other contaminants. The question arose regarding contaminants in themselves which has already been discussed by another group. We believe that this area needs further study in detail, not only from the standpoint of physical impacts on freshwater species suitable for culture, but also to dispel negative public perceptions that there could be problems, even when problems do not exist. People simply will not buy the animal if they feel that the quality is compromised. For contaminated areas, some thought could be given to bait minnow production, which was mentioned earlier, where the animals will not be used for human food consumption.

For diseases and growth, one would probably expect, obviously, the same problems that other commercial fish producers in this country have at the present time.

In terms of market outlook, for many of our freshwater aquaculture species the market is good. There is a great demand in this country for channel catfish, for crawfish, and for shrimp (be it fresh water or marine). So the market potential is there. The market is also there for fee fishing, recreational activities within these zones, and waterfowl management.

Regarding polyculture, there are a number of freshwater species that can be successfully grown together. When we look at the viable commercial freshwater aquaculture industry within this country, there are no large-scale polyculture systems for food fish in operation. We need to take a close look at individual species first to determine if polyculture would be suitable. However, from the standpoint of using these impounded sites for recreational fishing, the concept of polyculture, a multi-species culture, has a great deal of merit.

The general consensus of the panel and the individuals who participated in the discussion is that the technology is there for putting these sites into production for freshwater aquaculture. We have a commercially viable freshwater aquaculture industry within this country. We should go with pilot studies. I do not think a great deal of research is needed to culture freshwater organisms, and we can utilize the results of the pilot studies directly. The work by Mr. Milligan on the marine shrimp was very intriguing; I think

this is what we need in investigating the potential of using these containment sites for freshwater aquaculture.

The Corps of Engineers basically has to make a decision as to how this is going to be approached, working with and in cooperation with industry, with academia, and so forth. I think a lot of input and leadership will be required from the Corps of Engineers. As I mentioned earlier, each site will have to be looked at on a site-specific basis regarding whether or not the area will be suitable for culture of a particular species.

MARICULTURE AND CONTAMINANTS IN DREDGED MATERIAL

Summary Comments of Dr. James Andreasen, Co-Moderator

It was the general consensus of our group that there is a great potential for beneficial use through aquaculture of what has previously been considered an environmental problem. Federal agencies should develop basic guidelines for assessing potential contaminant problems and recommendations and should initially share the responsibility with culturists for determining the potential for contaminant uptake by organisms. It was the general belief in our group that there are enough data available to help with site and organism selection from programs such as the Dredged Material Research Program, the Ocean Disposal Program, and research that has been done in the last few years.

We must realize that we do not know much about long-term sublethal effects of contaminated dredged material on cultural organisms. Even if there is contaminant uptake, however, there is still a potential for raising bait species that would not be consumed by humans, so the potential for economic benefit might still be there.

Many areas of aquaculture have proceeded from research to development to extension services. With aquaculture in contaminated DMCA's we are still in the research and just starting the developmental phase. It may be rushing things to try to move into aquaculture in known contaminated DMCA's.

There are a lot of data available in the literature and from ongoing research. These data need to be applied to aquaculture. We would recommend the following:

a. An extensive literature search to document known contaminant effects on cultured organisms and testing procedures.

b. A survey of current research projects to provide some indication of how these results could contribute to our existing knowledge of contaminant effects. An identification of data gaps would come from this.

This information should be disseminated to all researchers who are interested in the problem of using contaminated DMCA's in aquaculture. Additional meetings where researchers and interested parties could come together and discuss research and progress would be useful to direct research. Following this, we believe there could be the development of operational guidelines for potential users of known contaminated DMCA's.

Summary Comments of Mr. James Mansky, Co-Moderator

The potential for contamination of culture organisms by contaminants in dredged material is real. As a first step, testing for known contaminants should be established to separate known contaminated DMCA's from potentially usable areas. Knowledge about contamination of an area does not automatically disqualify the area for aquaculture: the contaminant(s) may not be biologically available and, even if biological transfer is demonstrated, an area

could still be used for raising bait species. This group discussed who should have the responsibility for measuring the potential sediment contaminants in DMCA's and assessing the potential for bioaccumulation of these materials by organisms.

The potential mariculturist has to realize that the initial efforts in using contaminated DMCA's will entail significant risks, but our group felt that the Corps of Engineers should do all it can to let the culturist know what materials are in the sediments and what the potential for uptake of these materials might be. However, since containment area aquaculture will be a for-profit venture, the culturist needs to ensure that he will have a saleable product at the end of the growing season. So, in reality, two kinds of testing will be required: (1) initial testing for known contaminants to determine if mariculture is possible at a particular project site, and (2) the finished product testing to see if it is marketable.

Private laboratories are available that can test for contaminants in both the product and the sediments. A major problem is that standard methods are not yet established whereby we can predict that a certain level of a contaminant in sediments or water will accumulate to a certain level in the organism. Some Federal agencies do inspect seafood products to ensure their palatability and that they meet Federal Department of Agriculture action limits for certain materials. The Corps, or some other group, should draw up a set of guidelines in regard to contaminant testing procedures and product requirements for potential culturists.

It was pointed out by one participant that any scientific project goes through an evolution from research, to development, and then into an extension phase where the information is given to the public. Generally, aquaculture is in the development phase, but available information is not yet widely disseminated. In particular, the question of contaminants has not been addressed by the aquaculture industry.

Several of the issues raised by this group dealt with liability for contaminants by different governmental groups but we did not have the expertise to discuss the legal aspects relevant to this subject.

ECONOMICS OF CONTAINMENT SITE CULTURE

Summary Comments of Mr. Michael Johns, Moderator

Our discussion of the economics of growing shrimp in dredged material disposal sites concentrated on capital costs. One of the major concerns was the permitting process, not so much the actual cost of the permits, but the cost in the time required to obtain permits for aquaculture sites. Suggestions by Corps of Engineer participants were that perhaps Corps involvement could streamline the permit-granting process as more aquaculture ventures get started. A starting place in streamlining the permitting process is the fact that these containment sites are more or less Federally controlled. Some of the permit requirements may be circumvented.

Financing is an area of concern for everyone involved in any agriculture or aquaculture venture. Development of containment area aquaculture may open new avenues to Federal, State, or local financing that would come about due to the involvement of the Corps in demonstrating the feasibility of this concept.

We saw very few problems with land availability and cost. A major concern was the location of some of these sites with respect to access and security of the areas. We also considered savings in construction costs, mainly levee and dike construction. Once the overall dike has been constructed by the Corps in most of these facilities, some cooperative programs could be developed with the Corps of Engineers as far as erecting the inner levees. Operating costs depend on the specific organism to be cultured. My expertise is with shrimp, so I tended to concentrate there. We had some catfish growers who discussed that area. There are possibilities for operational cost savings, depending on the site. You could also have some additional costs. Here we get back into site location. If the site is in a very remote area, the cost of obtaining labor and operating costs at a remote site may be somewhat increased. We also looked at market economics. Here again, location plays a very great part on getting the product back into the market area.

Another consideration was consumer acceptance of a product that was raised in a dredged material containment site. Here we run into consumer education (e.g. this product has been passed by the USDA; it is a good product). That will definitely make an economic impact that will help sell these products.

As far as costs and benefit to the Corps of Engineers and the local community, one of the possible costs or additional costs to the Corps could be the construction of the inner levees. The costs could be shared under a cooperative program with the operator.

Another benefit would be that the Corps would probably get the use of additional sites for disposal operations.

As for costs to the local community, we have to look at alternative use for the land. Is aquaculture taking this land out of duck-hunting production or some other more valuable use? That is a question that would come up in assessing any agricultural venture. What alternative use could be made of this land? Is that use better than the use that we are putting it to now?

Benefits to the local community are the creation of jobs and the utilization of support industries, equipment industry, and certain service organizations.

We also looked at risk involved in setting up operations in dredged material containment sites. One potential problem was the reuse of these sites for dredged material. Since the Corps has gone into a program of long-term planning of disposal operations, operators could know when the cycle of reuse for certain sites should come about and plan accordingly.

In summary, the areas of economic concern are (1) the length of time to obtain permits, (2) the remoteness of some facilities which would add to the cost of producing animals in these areas, and (3) the consumer acceptance of the product and consumer education.

For additional research, we need cooperative ventures to determine the potential of these sites. This requires pilot studies, joint ventures between industry and the government agencies that would be involved. Educating the public as to the productivity of dredged material disposal sites and the products that would come from these is also an area to be explored.

LEGAL ASPECTS OF CONTAINMENT SITE MARICULTURE

Summary Comments of Mr. Bart Theberge, Moderator

When you talk about the legal aspects, you have to realize that the legal system defines a relationship between competing uses, and aquaculture is a relatively new competing use. Although we have things like the National Aquaculture Act, the current legal framework does not really reflect some of the concerns of aquaculture and processes that may aid the development of aquaculture. State law more than Federal law reflects this.

It is important to identify and assess potential legal problems and then deal with those that cause concern. In an open discussion I fear that we perhaps missed a few things, but my summary reflects the views of the people who were assembled in our group.

Aquaculture seems to be in a phase where there is overlapping scientific and technological development, overlapping development of business infrastructure, and overlapping of legal and institutional frameworks. We first discussed the political status of the industry. We discussed the political organization of aquaculturists and it seems that in many states there are too few aquaculture concerns to make a state-wide political organization effective. At the national level, there is some division of opinion among the World Mariculture Society members as to the wisdom of engaging in lobbying activities. That should be resolved.

One of the obvious major problems is that jurisdiction over aquaculture is very fragmented. Federal, State, and local entities are involved in aquaculture activities. As it has been pointed out earlier, there is a great deal of variation among states. Some states are very restrictive (Massachusetts was given as an example of a restrictive state) and there are some states which are, to be tactful, less restrictive. Texas was given as an example of one state that is less restrictive. In coming from a state whose laws are oriented toward traditional commercial fishing activities, I see problems for aquaculture activities. The laws were just not designed to accommodate aquaculture. There is also a great deal of ambiguity in our laws.

Although there may be few state laws addressing aquaculture, that can be either a good or a bad thing, as far as investment in aquaculture is concerned. If the lack of legal structure allows you latitude to pursue your goals, it's probably a good thing. But if this lack creates enough ambiguity to dampen investment interest, then it's a bad thing.

We also looked at some specific categories of aquaculture activities that were suggested earlier in this meeting. We looked at sites, stocking, predator and disease control, feeding, water quality, contaminants, harvest, processing, and sale aspects of aquaculture.

For sites, the belief in our committee was that permit streamlining was certainly needed. It was pointed out that this was being attempted at the Federal level. There's an even greater need for it at the state level since there's such variation among states. As far as the sites themselves are concerned, the consensus was that the culturist would be dealing with existing, confined upland sites. The primary parties involved would be the sponsor or

owner, the aquaculturist or entrepreneur, and the Corps of Engineers--that eliminates some legal problems from the very onset. One of the issues that we discussed in some detail were the limits of Corps authority. How far could the Corps go in encouraging or promoting aquaculture? Upland confined sites, as opposed to inundated sites, would be much easier for the Corps to promote.

Stocking was certainly a hot issue for several reasons. Even though state and Federal governments are involved, it was seen as primarily an issue between the state and the entrepreneur. At the Federal level, an executive order under the Carter administration discouraged use of nonnative or exotic species. I'm not certain of the status of that executive order under the current administration. In addition, there are Federal statutes that deal with injurous species, with the Department of the Interior in a lead role. Finally, there are state statutes.

Discussion was held concerning use of wild stock. We had a split among the people in our group: some entrepreneurs would not touch wild stock while others were making some use of it. In some states there are problems with ownership of wild stock. For example, someone from South Carolina mentioned that, even though it is permitted to capture wild stock and use it in their ponds, this stock was considered to be subject to public taking. The only protection the culturist had was that people would have to trespass on their private property to take this stock. Other members stated that their states had opposite rulings.

Predator and disease control, feeding, and contaminants were all considered in the context of water quality and were viewed as primarily state concerns or issues that would be worked out between the entrepreneur and the state, even though many of these things have a Federal involvement of some degree or another. Contaminants generated another concern, and that is concern over the quality of the product itself in light of Federal regulations. Depending on the organism, specific programs may apply. For example, if the products are shellfish, the Federal National Shellfish Sanitation Program sets the quality standards. Many of the potential legal aspects we discussed applied to specific sites, specific organisms, and even specific culture techniques.

We talked about harvest, where primarily state regulations apply. In some states, there are even barriers and restrictions there for aquaculture. Sale, transportation, and processing usually have state and some Federal involvement. Processing especially involves Federal regulation.

The degree of Corps involvement in aquaculture activities was a rather interesting element. On one hand were the aquaculturists and entrepreneurs recognizing that the Corps had limits to its involvement, but evidencing a rather strong interest in seeing the Corps increase its involvement in promoting this type of program, perhaps by amending or modifying traditional Corps of Engineers' activities or roles. The aquaculturists also seemed to favor broader definitions of "public interest" and "multiple use" than some of the people in the Corps have at the present time.

One of the things to come out of the discussion of Corps involvement was an interest to see a phased analysis of dredged material by the Corps of Engineers. Apparently at the present time the Corps of Engineers analyzes the dredged material on a one-shot basis. But, for the purposes of aquaculture, it was seen as desirable that when the Corps goes back to an area to

fill it, the Corps would run additional tests to give both the Corps and the aquaculturist more information as to what new or unusual materials might be present. Of course, the aquaculturists recognize that it is to their benefit to have initial tests made under any circumstances. Since many of these disposal and culture activities will probably move in some type of phased sequence (in other words, an aquaculturist may go in there and practice aquaculture for 3-5 years, then the Corps may use the facility again, and the aquaculturist might have to move to a new area, perhaps use an adjacent area, or come back to the old area), there was a desire expressed that sequential analysis of material be carried out.

In summary, the general consensus was that the main problem we were addressing was the unavailability of sites for aquaculture. That may be more of an expression of aquaculturist interest than Corps. Of course, I think it's fair to say from the discussion this morning that the Corps people saw disposal sites being increasingly difficult to come by. If indeed there's any way to facilitate creating new sites, then such endeavors are worthwhile--and that's the connection between aquaculture and disposal sites.

It was generally believed that this is a viable approach with no exceptional legal difficulties foreseen. It has already been carried out to some degree, so there is some precedent. The legal groundwork has been laid. On the part of the entrepreneurs, my own assessment of their discussions this morning was that it was certainly worth the risk.

QUESTIONS AND ANSWERS

Peter Pershbocker (Texas A&M): Yesterday Mr. Dugger mentioned that the primary problem with the permitting process was at the national level; then Mr. Johns mentioned that there was a major problem in the time involved there. It seems that the states are probably more cooperative than the Federal government, and perhaps work needs to be done at the Fish and Wildlife and Corps level to try to streamline. This is where the large improvements could be made, perhaps.

Mr. Theberge: I really can't make much more than a comment. I am under the impression now that the Corps is trying to meet the 60-day limit on permits. As far as the states are concerned, I think you're going to find a wide variability. My own impression in Virginia is that if you went there with a proposal for aquaculture, you'd probably spend an incredible amount of time being shuttled around from agency to agency. Not only agency to agency, but, in our case, our marine agency is located in the coastal zone, and the rest of the agencies are located in Richmond, which is in the middle of the state. So you're going to be covering a lot of geography in our state before anybody can really tell you conclusively what you can and can't do. We're just not structured to do it.

Peter Pershbocker: I'm aware of the way Districts have worked with the states and the agencies within their states in the past, and it seems like every Corps office responsible for its own geographic region has evolved a process of cooperation, a way of doing things with the state agencies, with which potential operators would react. Sometimes they have evolved a very, very efficient yet simple system, designed to make it quick, efficient, and

less frustrating for the permittee. I've seen presentations from representatives of the State of Georgia, the Department of Natural and Environmental Resources, who were setting as an example the cooperative relationship that exists between the Georgia D&R and the Savannah District. There is even some talk about revising 404 guidelines and streamlining the process to make it quicker.

Don Moore (National Marine Fishery Service): For the second year now, the oil and gas industry in Texas and Louisiana is getting together a workshop where all the agencies involved in regulating the industry and advising the regulatory agencies get together with their membership to ask questions and gain knowledge of what they do or don't have to do. The organization is the Wetland Energy Producers Association, called that since all of the oil and gas industries occasionally have to operate in wetlands. They have their own workshop where they show members how to apply for permits for these more closely regulated wetland operations. My thoughts are that we might think about a similar type of approach.

Durwood Dugger (Commercial Shrimp Culture International): I think there have been several workshops where aquaculturists and regulating agencies got together for this purpose and, as far as I know, little, if anything, has come out of them as far as direct changes in policies. Summarizing what I said before, our major problem was with U.S. Fish and Wildlife; they just have a standing policy of no aquaculture in a coastal zone. Short of the wholesale slaughter of the U.S. Fish and Wildlife, I don't know what can be done.

Addison Lawrence (Texas A&M): We held a permit workshop in Corpus Christi, Tex., where we invited most of the state agencies and as many of the Federal agencies as we possibly could to discuss mariculture. The gist of the outcome was that, using the EPA for example, aquaculture is too small an industry for them to really be concerned with, and that the philosophy of a culturist is to maintain water quality at such a level that what he is discharging into the natural waters is probably of higher quality for biological growth than what he took in. If he doesn't do this, he's not going to be in operation next year. The general conclusion from the conference was that aquaculture, in general, was not a real concern of the permitting agencies in terms of water quality being discharged.

Mr. Theberge: I can echo that, too, from my own state. There have been a few permits issued for aquaculture activities under the MPDS program. The state water quality officials are very relaxed about the extensive aquaculture activity simply because it seems to produce a water quality that is higher than the normal wwater quality.

CONCLUSIONS

The conclusions of the plenary session and group discussions were that aquaculture in active DMCA appears to be a feasible, cost-effective, and compatible multiple use of DMCA. With rare exceptions, currently available technology can probably be directly applied to DMCA aquaculture, making the concept practical with little additional research and development investment required.

Aquaculture as a secondary use of DMCA has potential to be both profitable and desirable. Demonstration projects under varying field conditions and research directed at the potential problem areas are recommended. Field demonstrations would ideally be conducted as joint ventures between industry and the government agencies that would be involved. The thoroughly documented results of field trials would provide the springboard to greater acceptance of the concept by industry, dredged material managers, and the owners of potential DMCA acreage. The potential for cost savings appears to exist both in those cases where the local sponsor furnishes the disposal areas and in those instances where the Federal government is responsible for furnishing and operating disposal areas. In the significant instances where the Federal government is the dredging project's sponsor, and holds title to DMCA acreage used by the project, the government could lease the acreage to aquaculturists under conditions that would ensure multiple beneficial use of the real estate. Lease fees could be (a) returned to the General Treasury, (b) returned to the CE to reduce project costs, (c) managed to assist local or regional economic development through contributions to social assistance or Civil Works construction programs, (d) applied toward regional or national environmental enhancement or mitigation, or (e) any combination of the above. Those problem areas and research needs identified during the workshop are considered tractable and would not hinder the application of this concept. The technical information shared at the workshop and the support generated for this concept by the represented agencies and interests provide a solid foundation for the further development of DMCA aquaculture.

WORKSHOP ATTENDEES

David Aldrich
Texas A&M University/Galveston
BLDG 311 Ft. Crockett
Galveston, TX 77550

James K. Andreasen
P. O. Box 2087
Victoria, TX 77902

James Bajec
U. S. Army Corps of Engineers
New England Division
424 Trapelo Rd.
Waltham, MA 02254

Bob Bass
U. S. Army Corps of Engineers
Galveston District
P. O. Box 1229
Galveston, TX 77553

Charles Belin, Jr.
U. S. Army Corps of Engineers
Savannah District
Environmental Resources Branch
P. O. Box 889
Savannah, GA 31402

John Bellinger
U. S. Army Corps of Engineers
Board of Engineers for Rivers and Harbors
Environmental Division
Kingman Building
Ft. Belvoir, VA 22060

A. Brown, Jr.
Address Unknown

James Buckner
P. O. Box 699
Anahuac, TX 77514

Charles Caillouet, Jr.
National Marine Fisheries Service
Galveston Laboratory
4700 Ave. U
Galveston, TX 77550

Charles Calhoun
U. S. Army Corps of Engineers
Waterways Experiment Station
P. O. Box 631
Vicksburg, MS 39180

Paul Carangelo
P. O. Box 1361
Port Aransas, TX 78373

George W. Chamberlain
Texas A&M University Mariculture Facility
4301 Waldron Rd.
Corpus Christi, TX 78418

Brian Chapman
Department of Biology
Corpus Christi State University
6300 Ocean Dr.
Corpus Christi, TX 78412

Larry Cook
U. S. Army Corps of Engineers
Lower Mississippi Valley Division
P. O. Box 80
Vicksburg, MS 39180

Hildon Davis
U. S. Army Corps of Engineers
Nashville District
P. O. Box 1070
Nashville, TN 37202

John Dean
Belle Baruch Institute for Marine Biology
University of South Carolina
Columbia, SC 29208

Cleve Die
Box 805
Alvin, TX 77511

James Dillard
Department of Agricultural Economics
P. O. Box 5187
Mississippi State University, MS 39762

Durwood Dugger, President
Commercial Shrimp Culture International, Inc.
P. O. Box AK
Port Isabel, TX 78578

H. Glenn Earhart
U. S. Army Corps of Engineers
Baltimore District
P. O. Box 1715
Baltimore, MD 21203

Gary Earls
U. S. Army Corps of Engineers
Southwestern Division
1114 Commerce St.
Dallas, TX 75242

Diane Findley
U. S. Army Corps of Engineers
Mobile District
P. O. Box 2288
Mobile, AL 36628

Clark T. Fontaine
National Marine Fisheries Service
Galveston Laboratory
4700 Ave. U
Galveston, TX 77550

Gregg Gitschlag
National Marine Fisheries Service
Galveston Laboratory
4700 Ave. U
Galveston, TX 77550

Arthur B. Gould
U. S. Army Corps of Engineers
Charleston District
P. O. Box 919
Charleston, SC 29402

Wade Griffin
Department of Agricultural Economics
Texas A&M University
College Station, TX 77843

Richard Harrison
U. S. Army Corps of Engineers
Galveston District
P. O. Box 1229
Galveston, TX 77553

Paul M. Hathorn
U. S. Army Corps of Engineers
Fort Worth District
P. O. Box 17300
Ft. Worth, TX 76102

Richard E. Highfill
USDA Soil Conservation Service
P. O. Box 2890
Washington, DC 20013

Henry Hildebrand
Address Unknown

Donald H. Hill
U. S. Army Corps of Engineers
Charleston District
P. O. Box 919
Charleston, SC 29402

Paul Hitchens
Tamu/Hatchery Section
NMFS Galveston Lab
4700 Ave. U
Galveston, TX 77550

Norma Hockford
8510 Long Point Rd.
Houston, TX 77055

Ronald G. Hodson
105-1911 Bldg.
North Carolina State University
Raleigh, NC 27650

Hoyt W. Holcomb, Jr.
P. O. Box 1117
Angleton, TX 77515

William Hollerman
Department of Fisheries and
Aquacultures
Auburn University
Auburn, AL 36849

Jurij Homziak
U. S. Army Corps of Engineers
Waterways Experiment Station
P. O. Box 631
Vicksburg, MS 39180

Hann-Jin Huang
Texas A&M University
Cedar Bayou Mariculture Laboratory
5602 Ave. S #8
Galveston, TX 77550

Alex Iskander
U. S. Army Corps of Engineers
Cold Regions Research and Engineering
Laboratory
P. O. Box 282
Hanover, NH 03755

Rex Ito
Texas A&M University
Shrimp Mariculture Laboratory
3102 Ave. R #5
Galveston, TX 77550

Bill Jackson
National Marine Fisheries Service
Galveston Laboratory
4700 Ave. U
Galveston, TX 77550

Michael A. Johns
Texas A&M University Shrimp
  Mariculture Facility
4301 Waldron Rd.
Corpus Christi, TX 78418

Sterling K. Johnson
Department of Wildlife and Fisheries
  Science
Texas A&M University
College Station, TX 77843

David Kendall
U. S. Army Corps of Engineers
Waterways Experiment Station
P. O. Box 631
Vicksburg, MS 39180

Edward Klima, Director
NMFS, Southeastern Fisheries Center
Galveston Laboratory
4700 Ave. U
Galveston, TX 77550

Frank Kuban
Texas A&M Shrimp Mariculture Program
National Marine Fisheries Service
4700 Ave. U
Galveston, TX 77550

Carolyn Lare
A-7 Fish
5518 Telephone
Houston, TX 77087

COL Alan L. Laubscher, District
  Engineer
U. S. Army Corps of Engineers
Galveston District
P. O. Box 1229
Galveston, TX 77553

Addison L. Lawrence
Texas A&M University
Marine Experiment Station
Port Aransas, TX 78373

Jeorge Leong
Gulf Coastal Fisheries Center
Aquaculture Division
NMFS
4700 Ave. U
Galveston, TX 77550

John Lunz
U. S. Army Corps of Engineers
Waterways Experiment Station
P. O. Box 631
Vicksburg, MS 39180

Dorothea C. Mangum
Texas A&M at Galveston
P. O. Box 1675
Galveston, TX 77553

Roger Mann
Department of Biology
Environmental Systems Laboratory
Woods Hole Oceanographic Institution
Woods Hole, MA 02543

James Mansky
U. S. Army Corps of Engineers
New York District
26 Federal Pl.
New York, NY 10278

Rick Medina
U. S. Army Corps of Engineers
Galveston District
P. O. Box 1229
Galveston, TX 77553

Russell Miget
Sea Grant Marine Advisory
Texas A&M University
Galveston, TX 77553

Dennis Milligan
Dow Chemical USA
Texas Division
Freeport, TX 77541

John Miloy
Texas Coastal and Marine Council
P. O. Box 13407
Austin, TX 78711

Thomas Minello
National Marine Fisheries Service
Galveston Laboratory
4700 Ave. U
Galveston, TX 77550

R. Vernon Minton
Marine Resources Division
Alabama Department of Conservation
  and National Resources
Claude Peteet Mariculture Center
P. O. Box 458
Gulf Shores, AL 36542

Cornelius Mock
Gulf Coastal Fisheries Center
Aquaculture Division
4700 Ave. U
Galveston, TX 77550

Dennis Moon
Moon Aquaculture Foods
P. O. Box 3941
Port Arthur, TX 77640

Ronald Moon
Moon Aquaculture Foods
P. O. Box 3941
Port Arthur, TX 77640

Donald Moore
NMFS Environmental Assessment
Galveston Laboratory
4700 Ave. U
Galveston, TX 77550

Keith A. Newlin
Tamu Shrimp Mariculture Facility
Galveston Hatchery Section
3102 Ave. R #5
Galveston, TX 77550

John Null, Jr.
PISCES
3826 Bentwood Ln.
Galveston, TX

Jack Parker
Laquna Madre Shrimp Farms
3117 Jacarranda
Harlingen, TX 78550

Tom Patin
U. S. Army Corps of Engineers
Waterways Experiment Station
P. O. Box 631
Vicksburg, MS 39180

Peter Persbacher
Texas A&M Cedar Bayou Laboratory
P. O. Box 1396
Baytown, TX 77520

Jesse Pfeiffer
U. S. Army Corps of Engineers
Office of the Chiefs of Engineers
Casimir Pulaski Bldg.
20 Mass Ave., NW
Washington, DC 20314

Edward J. Pullen
U. S. Army Corps of Engineers
Coastal Engineering Research Center
Kingman Building
Ft. Belvoir, VA 22060

Gerald Rapp
Planning Department
City of Port Arthur
P. O. Box 1089
Port Arthur, TX 77640

Sammy M. Ray
Marine Biology Department
Texas A&M University at Galveston
Bldg. 311 Ft. Crockett
Galveston, TX 77550

Maurice Renaud
National Marine Fisheries Service
Galveston Laboratory
4700 Ave. U
Galveston, TX 77550

Billy Roberts
Fred S. James Co. of Mississippi, Inc.
P. O. Box 9154
Jackson, MS 39206

Edwin Robinson
Department of Wildlife and Fisheries
Sciences
Texas A&M University
College Station, TX 77843

Robert Romaire
249 Agricultural Center
Louisiana State University
Baton Rouge, LA 70803

Anthony J. Rubino
Texas A&M University
Shrimp Mariculture Project
7501 Heards Ln. #341-A
Galveston, TX 77551

Norman I. Rubinstein
U. S. EPA Environmental Research
Laboratory
Sabine Island
Gulf Breeze, FL 32561

Mel Russell
Sea Grant Marine Advisory
Texas A&M University
Galveston, TX 77553

Paul A. Sandifer
South Carolina Wildlife and Marine Resources Department
Marine Resources Research Institute
P. O. Box 12559
Charleston, SC 29412

Robert Springborn
Texas A&M University
919 Northwood
Woodhollow 6110
Baytown, TX 77521

Robert Stickney
Department of Wildlife and Fisheries Science
Texas A&M University
College Station, TX 77843

R. Kirk Strawn
Department of Wildlife and Fisheries Science
Texas A&M University
College Station, TX 77843

Joseph Surovik
P. O. Box 86
Pt. Lavaca, TX 77979

Jim Tarr, President
PISCES
2608 Brom Bones
Pearland, TX

Henry Tatem
U. S. Army Corps of Engineers
Waterways Experiment Station
P. O. Box 631
Vicksburg, MS 39180

Walter M. Tatum
Marine Resources Division
Alabama Department of Conservation and Natural Resources
Claude Peteet Mariculture Center
P. O. Box 458
Gulf Shores, AL 36542

W. R. Taylor
Texas Department of Water Resources
P. O. Box 13087
Capitol Station
Austin, TX 78711

Bart Theberge
Virginia Institute of Marine Science
Gloucester Point, VA 23062

William C. Trimble
St. Martin Land Co.
Rt. 2 Box 56
Lafayette, LA 70507

John W. Tunnell
Corpus Christi State University
6300 Ocean Drive
Corpus Christi, TX 78412

Andre N. Van Chau
John E. Gray Institute
Lamar University
P. O. Box 10067
Beaumont, TX 77710

Sagrario B. Van Chau
Resettlement Office, Inc.
P. O. Box 6610
Beaumont, TX 77705

John E. Waldrop
Department of Agricultural Economics
P. O. Box 5187
Mississippi State University, MS 39762

James Weaver
National Fisheries Center Lee Town
Box 700
Kearneysville, WV 25430

James W. Webb, Jr.
Marine Biology Department
Texas A&M University at Galveston
Galveston, TX 77563

Thomas L. Wellborn, Jr.
Mississippi Cooperative Extension Service
Extension Wildlife and Fisheries Department
P. O. Box 5405
Mississippi State University, MS 39762

K. Wade Whittinghill
U. S. Army Corps of Engineers
Nashville District
P. O. Box 1070
Nashville, TN 37202

Joshua Wilkenfield
Texas A&M University
Shrimp Mariculture Project
Hatchery Section
NMFS Galveston Laboratory
4700 Ave. U
Galveston, TX 77550

Chuck Wilson
Belle Baruch Institute for Marine
  Biology
University of South Carolina
Columbia, SC 29208

Tom Wright
U. S. Army Corps of Engineers
Waterways Experiment Station
P. O. Box 631
Vicksburg, MS 39180

David Alan Yadon
Texas Agricultural Experiment Station
Texas A&M University
919 Northwood Dr. #7603
Baytown, TX 77521

William Younger
Sea Grant Marine Advisory
Texas A&M University
Galveston, TX 77553

Zoula Zein-Elden
National Marine Fisheries Service
Galveston Laboratory
4700 Ave. U
Galveston, TX 77550

Roger Zimmerman
National Marine Fisheries Service
Galveston Laboratory
4700 Ave. U
Galveston, TX 77550

END

FILMED

1-84

DTIC